Fuel Consumption and Emissions of Turnpike Doubles in the Canadian Prairie Region

By

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ABSTRACT

This research analyzes fuel consumption and emissions of Turnpike double trailer combinations (Turnpikes) on a regional network in the Canadian Prairie region. The research: (1) establishes current benchmarks for fuel consumption of Turnpikes and five-axle tractor semitrailers (3-S2s) with van trailers; (2) develops fuel consumption models for these vehicle types; (3) establishes an understanding of current operating characteristics of Turnpikes in the region; and (4) estimates their system-wide effects in terms of fuel consumption and emissions in Manitoba by applying the developed models.

Turnpike Doubles comprise two 16.2-metre (53-foot) trailers and therefore, can effectively haul twice the cubic freight of a five-axle tractor semitrailer (with one 16.2-metre tractor semitrailer). Turnpikes are routinely permitted to operate on all divided rural highways in the Canadian Prairie region. This network measures approximately 4,100 centreline-kilometres, consists of primarily uncongested highways, and serves a population base of about six million people.

Canadian Prairie region-based carriers were contacted for fuel consumption data and to complete a questionnaire. These companies operate a combined fleet of 2,200 tractors and 6,000 trailers. The responses revealed that these companies had a combined increase in Turnpike Double travel (from 2007 to 2009) in the Canadian Prairie Region of 44 percent after the twinning of the Trans Canada Highway was completed between Winnipeg and Regina in 2007.

Metrics that incorporate a freight task such as fuel consumed per average payload tonne-kilometre or per pallet-kilometre indicate the fuel consumption benefits of

Turnpikes. 3-S2s consume 3.4 litres per payload tonne-100 kilometres and Turnpikes consume 2.6 litres per tonne-100 kilometre, saving 24 percent on an average tonne-kilometre basis. On an average pallet-kilometre basis, 3-S2s consume 0.81 litres per pallet-100 kilometre and Turnpike Doubles consume 0.54 litres per pallet-100 kilometre, a savings of 33 percent.

The results of this research indicate that Turnpikes can save 28.7 litres per 100 kilometres when compared to two 3-S2s. Seasonal variations indicate higher fuel consumption in the winter months in both vehicle configurations. Winter fuel consumption savings from operating a Turnpike in place of two 3-S2s is about 30.7 litres per 100 kilometres. About 28.8 litres fuel are saved per 100 kilometres of summer operations.

The use of Turnpike Doubles (in 2009 on the 630 centreline-kilometre Manitoba Effective Turnpike Double network) reduced fuel consumption by an estimated 3.8 million litres per year and CO_2 emissions by an estimated 10.1 million kilograms per year.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 THE RESEARCH

This research analyzes fuel consumption and emissions of Turnpike double trailer combinations (Turnpikes) on a regional network in the Canadian Prairie region. The research: (1) establishes current benchmarks for fuel consumption of Turnpikes and five-axle tractor semitrailers (3-S2s) with van trailers; (2) develops fuel consumption models for these vehicle types; (3) establishes an understanding of current operating characteristics of Turnpikes in the region; and (4) estimates their system-wide effects in terms of fuel consumption and emissions in Manitoba by applying the developed models. The results of this analysis will assist civil engineers by providing information of the increasing activity of Turnpikes, their operational characteristics on the highway network in the Canadian Prairie region, and their effect on fuel consumption and emissions. This research defines fuel consumption as the volume of fuel used to move a vehicle in units of litres per 100 kilometres of travel.

1.2 BACKGROUND AND RESEARCH NEED

Energy consumption in Canada's freight transportation sector has grown by 61 percent between 1990 and 2005 due to increased use of heavy trucks and new supply chain requirements for just-in-time delivery (Natural Resources Canada, 2008a).

One of the most effective methods of conserving heavy truck fuel consumption and emissions is by utilizing more productive vehicles. Previous research has shown that Turnpikes can increase productivity and safety while reducing energy use, emissions, operating costs and truck kilometres travelled (Regehr, 2009; American Transportation Institute, 2008; L-P Tardif & Associates, 2006; and Woodrooffe, 2010). Turnpike Doubles comprise two 16.2-metre (53-foot) trailers and therefore, can effectively haul twice the cubic freight of a five-axle tractor semitrailer (with one 16.2-metre tractor semitrailer). These two vehicle types and their maximum vehicle lengths and gross vehicle weights (GVWs) are shown in Table 1.

Table 1: Vehicle Length and Weight Limits in the Canadian Prairie Region as of January 1, 2011

Vehicle	Maximum Length (metres)			Maximum GVW (tonnes)		
	AB	SK	MB	AB	SK	MB
Five-axle tractor semitrailer (3-S2) 	23.0	23.0	23.0	39.5	39.5	39.5
Turnpike Double 	40.0	41.0	41.0	63.5[a]	63.5[a]	62.5[a]

Notes: [a] For eight or more axles
Maximum length and GVW limits are for primary highways.
Turnpike Doubles are specially permitted to operate on twinned highways in the Canadian Prairie region.

Sources: Governement of Alberta (2010), Manitoba Infrastructure and Transportation (2010), Saskatchewan Highways and Infrastructure (2010).

Turnpikes are typically used for low-density freight (density <15 lb/ft^3). These vehicles operate under special permits granted by provincial jurisdictions to improve the technical productivity of transporting low-density commodities. They are limited to speeds of 100 kilometres per hour and operate on primarily uncongested highways. In the Canadian Prairie region, a relatively favourable regulatory environment, expansion of the network on which they are permitted to operate, rising demand for hauling low density commodities, and an economic recession have generated an increase in the use of these higher productivity vehicles. A study by L-P Tardif & Associates Inc. (2006) collected fuel consumption data for Turnpike Doubles and found savings of approximately 28 litres per 100 kilometres per Turnpike Double movement compared to operating two five-axle tractor semi-trailers with dry or refrigerated van trailers. However, there is still limited knowledge regarding the relationship between GVW and fuel consumption, when Turnpikes are used. There is also limited knowledge regarding the seasonal characteristics of fuel consumption for these vehicle types.

As the highway system is designed, operated, and maintained by transportation engineers to accommodate the users of the road, the presence of Turnpike Doubles creates challenges for transportation engineers in terms of safety, infrastructure design and maintenance, traffic operations, and fuel consumption and emissions. Governments and the public are becoming increasingly concerned with energy security and climate change, so engineers must design, develop, and implement transportation systems that address these concerns. This research is conducted to improve the understanding of fuel consumption and emissions characteristics of Turnpikes, particularly compared to 3-S2s. In addition, it develops an understanding of fuel consumption and emissions of the exposure of Turnpikes in the Canadian Prairie fleet mix.

1.3 OBJECTIVES AND SCOPE

The objectives of this research are to:

1. Understand the fuel consumption and emissions characteristics of five-axle tractor semitrailers and Turnpike Doubles in the Prairie region.

2. Characterize aspects of the transportation system affecting heavy truck fuel consumption and emissions, including the roadway network, the vehicle types

and their operating characteristics, technologies, and emission regulations and initiatives.

3. Collect data on fuel consumption and technologies to reduce fuel consumption from Canadian Prairie region-based carriers.

4. Develop a methodology to create fuel consumption models for Turnpike Doubles and five-axle tractor semitrailers.

5. Analyze fuel consumption and emissions effects of Turnpike Doubles in Manitoba.

The scope of the research is defined by data on fuel consumption acquired from carriers in the Canadian Prairie region that operate both vehicle classes and their use of technologies and practices to reduce fuel use and emissions. Fuel consumption data are analyzed in terms of the gross vehicle weight, cube, and season.

1.4 RESEARCH METHODOLOGY

The methodology to design fuel consumption models is based on the transportation systems analysis approach. This approach describes the dynamic inter-relationship between the transportation system, the demand for transportation, and the resulting flows of goods including the resources consumed to accomplish this task. For this research, these fundamentals are applied to the context of heavy truck fuel consumption and emissions of Turnpike Doubles and five-axle tractor semitrailers. This research focuses on the interrelationship between the transportation and flow system while the demand for transportation remains constant.

The research methodology is shown schematically in Figure 1. The methodology guides the data collection and analysis efforts. It is comprised of three main components, which are identified as part of either the transportation system (*T*) or flow system (*F*). The following subsections describe each component and reference other sections of this thesis where further details are provided.

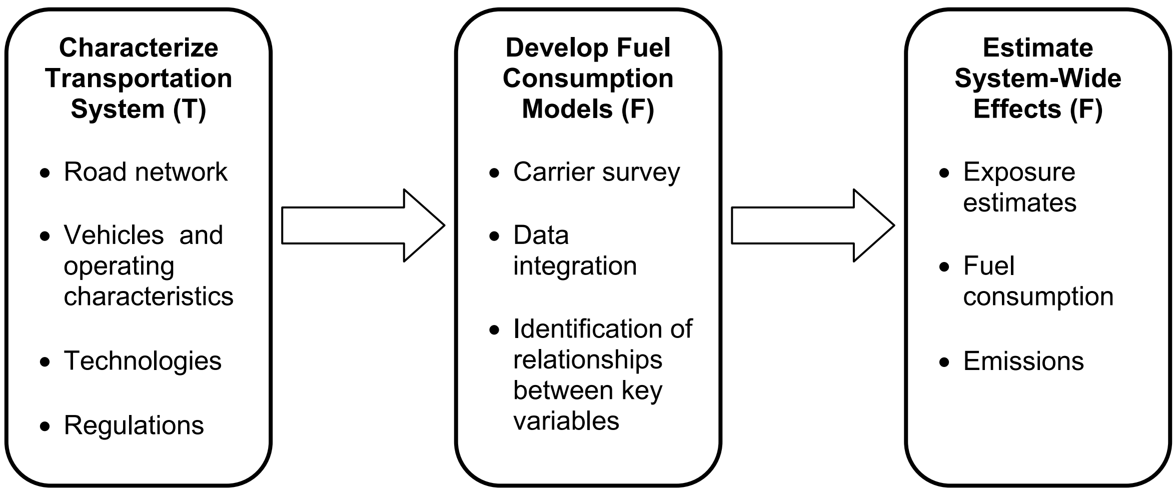


Figure 1: Research Methodology

1.4.1 Characterize Transportation System

The first component of the methodology characterizes relevant aspects of the transportation system, *T*, for understanding fuel consumption aspects of Turnpikes. Four elements are characterized (the road network, technologies, emissions regulations and initiatives, and vehicle and operating characteristics,).

- *Road Network:* The definition of the road network directs the subsequent data collection and analysis. This research defines the road network as a subset of the network of provincial highways, in the Prairie region, on which Turnpikes are permitted to operate. This is addressed in Section 3.1.

- *Technologies:* Information about technologies employed to reduce heavy truck fuel consumption is based on the literature review and a survey of carriers that operate Turnpikes in the Canadian Prairie region. This is addressed in Sections 2.5 and 3.3

- *Emissions Regulations and Initiatives:* Regulations on emissions force the development of cleaner fuels, technologies, and fleet operational practices. This is supported by government initiatives to provide information and financing to develop incentives for carriers to reduce emissions. This is addressed in Section 3.2.

- *Vehicles and Operating Characteristics:* Understanding fuel consumption characteristics of Turnpikes is meaningful if direct comparisons are made to 3-S2 vans, as one Turnpike can haul as much cubic freight as two 3-S2 vans. These vehicles differ in terms of weights, dimensions, axle configuration, and performance. This is addressed in Section 3.4.

1.4.2 Develop Fuel Consumption Models

The second component of the research methodology develops fuel consumption models using data collected from carriers that operate Turnpikes and 3-S2 vans in the Prairie region. These data characterize the resource consumption aspect of the flow system, *F*. Flow system variables relevant to the context of heavy truck fuel consumption and emissions are:

- *Traffic volume,* measured as the average annual daily truck traffic (AADTT) of Turnpike Doubles and five-axle tractor semitrailers.

- *Weight* of axles, vehicle tare, payload, and gross.

- *Cubic dimensions* of payload and trailer capacity.

- *Operating speed* of the vehicles.

- *Fuel consumed,* expressed as "litres per 100 kilometres", represents the energy resources required to operate these vehicles.

- *Emissions* of carbon dioxide, carbon monoxide, nitrous oxides, sulphur oxides, particulate matter, hydrocarbons, and methane. The emissions represent consumed air resources.

Each of the variables can be further described in terms of time, space, and vehicle characteristics.

The fuel consumed and emissions are described as a function of exposure. The metrics used to track and evaluate resource consumption are expressed in terms of exposure variables. For example, fuel consumption is typically expressed in terms of "litres per 100 kilometres" or "miles per gallon". For trucks, this metric is sometimes extended to include weight and cubic dimensions. Expressing resource consumption for specific times, places, or vehicle characteristics can further refine exposure metrics, for example fuel consumption by season.

The flow system variables are used to develop the fuel consumption models. Data on fuel consumption, for the operation of Turnpikes and 3-S2s between 2006 and 2009 (inclusive), are collected from major trucking companies based in the Canadian Prairie region. These companies represent a total operation of about 2,200 tractors and 6,000 trailers. Due to a confidentiality agreement, the number and names of the companies cannot be identified in this thesis document.

Since each carrier uses different methods, technologies, and data processes to track fuel consumption data; these data must be integrated and normalized. The analysis of the normalized dataset reveals relationships between the exposure variables (independent variable) and fuel consumption (dependent variable). The scope of the analysis and the capability of the fuel consumption models are constrained by limitations within the normalized dataset. The exposure variables identified in the analysis are: vehicle type, season, average payload weight, and cubic capacity.

1.4.3 Estimate System-Wide Effects

The third component of the methodology estimates system-wide effects of Turnpikes as compared to 3-S2 vans operating on a road network in Manitoba. There are three aspects to this estimation: (1) estimate truck exposure for Turnpikes and 3-S2s; (2) quantify fuel consumption; and (3) convert fuel consumption into emissions.

1.5 THESIS ORGANIZATION

The thesis is composed of five chapters. Chapter 2 summarizes findings from the literature regarding heavy truck energy use and emissions, and technologies and strategies to reduce fuel consumption and emissions.

Chapter 3 characterizes aspects of the transportation system affecting heavy truck energy use and emissions. The transportation system is described in terms of: (1) the road network; (2) vehicle and operating characteristics; (3) technologies; and (4) emission regulations and initiatives.

Chapter 4 develops the fuel consumption models for Turnpikes and 3-S2s based on: (1) the design and conduct of a survey of carriers that operate Turnpikes in the Canadian Prairie region; (2) integration and normalization of fuel consumption data obtained from carriers; and (3) identification of relationships between key variables affecting fuel consumption.

Chapter 5 provides the system-wide estimate of fuel consumption and emissions effects of Turnpikes in Manitoba. It describes Turnpike and 3-S2 exposure data sources and estimates and combines them with the models developed in Chapter 4 to calculate the system-wide effects of Turnpikes.

Chapter 6 presents conclusions and recommendations for future research.

1.6 TERMINOLOGY

The following is a list of definitions for terms used throughout this thesis.

Cube-Out: Truck trailer freight loading condition in which the trailer's volumetric capacity is filled before the vehicle's gross vehicle weight limit is reached.

Exposure: The number and nature of traffic events at a point or along a segment, in a specified time (Regehr, 2009).

Five-axle tractor semitrailer (3-S2): A single truck consisting of a tractor with one 16.2-metre semitrailer, subject to a vehicle length limit of 23.0 metres and a gross vehicle weight limit of 39,500 kilograms. Unless otherwise indicated, the term 3-S2 implies a dry or refrigerated van body type.

Fuel Consumption: Volume of fuel used to move a vehicle in units of litres per 100 kilometres of travel.

Fuel Efficiency: Fuel used to accomplish a specific freight or work task (Woodrooffe, 2010).

Heavy Truck: Any articulated combination using a truck-tractor for propulsion. Such combinations include two- and three-axle tractors with a single, tandem, or tridem axle semitrailer; a double-trailer combination; or a triple trailer combination. This also includes truck-tractors with no units attached (bobtails) (Montufar, 2002).

Turnpike Double (Turnpike): A multiple-trailer truck consisting of a tractor with one 16.2 metre van semitrailer and one 16.2-metre van trailer, subject to a vehicle length limit of 41.0 metres and a gross vehicle weight limit of 62,500 kilograms (Regehr, 2009)

Weigh-Out: Truck trailer freight loading condition in which the vehicle's gross vehicle weight limit is reached before the trailer's volumetric capacity is filled.

2. LITERATURE REVIEW

This chapter summarizes the literature review on heavy truck fuel consumption, emissions, efficiency metrics, and technologies and strategies to reduce fuel consumption and emissions.

2.1 DESCRIPTION OF LITERATURE SEARCH

A comprehensive literature search was conducted for sources dated 2000 and later. Since there has been a lot of development on fuel consumption and emissions of heavy trucks in the past ten years, literature prior to 2000 is not included. Data and information sources include: (1) research periodicals and journal papers; (2) conference proceedings; (3) readily available textbooks; and (4) documents on the World Wide Web. The search included the library catalogues, institutions, agencies, and resources shown below.

Special Library Catalogues

- Transportation Research Information System (TRIS)
- University of Manitoba Bison Catalogue

Government Agencies

- Environment Canada
- Natural Resources Canada
- Transport Canada

Research Institutions

- American Transportation Research Institute
- Heriot-Watt University Logistics Research Centre
- Rocky Mountain Institute

Scientific Research Journals

- Transportation Research Record
- Transport Research Part D

- US Environmental Protection Agency
- Manitoba Infrastructure and Transportation
- Council of Energy Ministers

Conference Proceedings

- Transportation Research Board

Special Interest Groups

- Union of Concerned Scientists

Industry Associations

- Canadian Trucking Alliance
- Manitoba Trucking Association

Trade Magazines

- Transport Topics

2.2 HEAVY TRUCK FUEL CONSUMPTION

- Kamakaté and Schipper (2008) look at the trends in truck energy use and emissions in countries of the Organization for Economic Co-operation and Development (OECD). As engine and truck technologies improve, "better overall handling of truck freight" can assist in providing future energy and emissions savings (p. 14). Furthermore, "obvious gains" will come from improving truck logistics, which includes "better matching of truck size and capacity to cargo load and type" (p. 14). Also of interest is that trucking in Japan is "more carbon intensive" due to a "large fleet of smaller vehicles carrying smaller load" (p. 10).

- McKinnon (2008) indicates that, since 1990, the development of truck engines has endured a slow rate of engine fuel consumption reduction. This is attributed to regulations to meet NO_x controls and other emission pollutants which tend to reduce the efficiency of the engine. The author identifies four factors that can achieve reductions in fuel consumption. These are:

- Vehicle design: The design of the vehicle itself can enhance energy efficiency in reductions in vehicle tare weight, improvements in engine exhaust systems, aerodynamic profiling, and reduced rolling resistance.

- Vehicle maintenance: Deficiencies in engine combustion, tire inflation, and axle alignment affect vehicle fuel consumption.

- Driver performance: Driving style influences the fuel efficiency of a fleet. Driver training is a cost-effective approach to mitigating fuel consumption from driver behaviour.

- Delivery scheduling: Traffic congestion can be avoided by scheduling deliveries in off-peak times rather than daytime and utilizing information and communications technologies to divert trucks to routes away from heavy traffic. Scheduling is often constrained by requirements to synchronize deliveries with production and distribution patterns.

* Ogburn and Ramroth (2007) indicate that on average, long haul operations use about 6.5 percent of the energy in each litre of fuel to move cargo and 4.5 percent for the tractor-trailer. A typical modern diesel truck will lose 56 percent of its fuel energy as heat through the exhaust and cooling systems, 19 percent to overcome aerodynamic drag, 12 percent to idling, 11 percent to tire rolling resistance, and two percent to drive train inefficiencies.

  The authors further identify that as vehicular velocity increases fuel consumption rises exponentially to overcome the forces of aerodynamic drag. At 105 kilometres per hour, two-thirds of the horsepower created by the engine is lost to overcoming aerodynamic drag. More than 60 percent of the aerodynamic drag on a tractor semitrailer is due to the trailer.

- L-P Tardif & Associates, Inc. (2006) finds that a Turnpike Double can replace two five-axle tractor semitrailers to save 28 litres of fuel per 100 kilometres of travel. This study utilizes the 1999 National Roadside Survey and the 1991-2001 Commercial Vehicle Survey (CVS) to determine the distance travelled by tractor semitrailers on multilane highways in Nova Scotia, New Brunswick, Quebec, and Ontario. Potential fuel and greenhouse gas (GHG) emissions savings generated by replacing tractor semitrailers with Turnpike Doubles are determined on the basis of this travel distance. Annual fuel use and emissions savings are estimated to be 260 million litres and 730 kilo-tonnes of GHG, respectively.

- Malzer (2005) researches fuel consumption and emissions of three truck types: five-axle tractor semitrailers, six-axle tractor semitrailers, and eight-axle B-trains. The author identifies that: (1) fuel efficiency in Western Canada varies by season; (2) fuel consumption by heavy trucks operating in rural Manitoba has decreased by approximately one percent per year between 1982 and 2002; and (3) fuel efficiency decreases by 0.0278 kilometres per litre per operating tonne.

- U.S. DOT (2004), in its *Western Uniformity Scenario Analysis*, analyzes the environmental effects attributable to a change in truck size and weight policy which would entail lifting the longer combination vehicle (LCV) freeze and harmonizing LCV weights, dimensions, and routes among the 13 western states already permitting LCV operations. Turnpike Doubles are one type of LCV configuration. These states are: Washington, Oregon, Nevada, Idaho, Utah, Montana, Wyoming, Colorado, North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma. LCVs operating under this scenario would be limited to a gross vehicle weight (GVW) of 129,000 pounds. This scenario would result in a 12 percent reduction in fuel consumption and emissions.

- Ang-Olson and Schroeer (2002) indicate that heavy trucks primarily operate diesel engines because they provide higher power per unit of fuel burned compared to gasoline engines. Technologies such as turbochargers and intercoolers have further increased diesel engine efficiency.

- Taylor (2001) indicates that pavement surface and condition affect fuel consumption. Smoother and more rigid pavements have lower rolling resistance than rough or soft roads. Rough pavements can increase heavy truck fuel consumption by 10 percent compared to smoother pavements. In summer, asphalt behaves more plastically and increases rolling resistance, the effects of which are more substantial for heavier loaded trucks. The difference in fuel consumption is measured to be eight percent between concrete and asphalt in warm weather conditions.

- U.S. DOT (2000), in its *Comprehensive Truck Size and Weight Study*¸ analyzes five illustrative truck size and weight scenarios to determine the relative magnitude of associated infrastructure effects. Three of these scenarios involve increases in GVWs:

  - North American Trade Scenarios, which would permit heavier GVWs on certain vehicles by increasing the allowable tridem axle load limit to either 44,000 pounds or 51,000 pounds. This would allow an estimated 6.2 and 6.3 percent decrease in energy costs for the 44,000-pound and 51,000 pound tridem axle weights respectively.

- Longer Combination Vehicles Nationwide Scenario, which would: (1) allow Turnpike Doubles (twin 53-foot combinations weighing up to 148,000 pounds), Rocky Mountain Doubles (combinations with one 53-foot and one 28.5-foot trailer weighting up to 120,000 pounds), triples (combinations with three 28.5-foot trailers weighing up to 132,000 pounds), and eight-axle twin trailer combinations (weighing up to 124,000 pounds) on a designated nationwide network; and (2) allow triples and eight-axle twin trailer combinations on a broader network. This would result in an estimated 13.8 percent decrease in energy costs.
- Triples Nationwide Scenario, which would allow Triples weighing up to 132,000 pounds on a designated nationwide network. This scenario would result in an estimated 12.8 percent decrease in energy costs.

2.3 HEAVY TRUCK EMISSIONS

- Environment Canada (2010a and 2010b) establishes the human health and environmental effects of heavy truck pollutants. Table 2 shows the primary pollutants produced by heavy truck diesel internal combustion engines, their source, and effect on human health and the environment.

Table 2: Heavy Truck Engine Emission Pollutants

Pollutant	Source of Pollutant	Effect
Carbon monoxide (CO)[1]	Incomplete carbon combustion	• GHG – climate change • Detrimental to human health
Nitrogen oxides (NO_x)[1]	High-temperature combustion of nitrogen in air-fuel mixture	• Ground level ozone • Acid rain • Contributes to PM formation • GHG
Particulate matter (PM)[1]	Incomplete fuel combustion	• Precursor to smog
Sulphur oxides (SO_x)[1]	Combustion of fuel containing sulphur	• Acid rain • Contributes to PM formation
Hydrocarbons (HC)[1]a	Partially burned fuel	• Ground level ozone • Detrimental to human health
Carbon dioxide (CO_2) [2]	Complete carbon combustion	• GHG – climate change
Methane (CH_4) [2]	Incomplete carbon combustion	• GHG – climate change
Nitrous Oxide (N_2O) [2]	Incomplete carbon combustion	• GHG – climate change

Note: [a] Hydrocarbons are also known as volatile organic compounds (VOCs)
Sources: [1] Environment Canada (2010a)
[2] Environment Canada (2010b)

The effects of the pollutants are explained as follows (Environment Canada, 2010a):

- Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) react with water in the atmosphere to form sulphuric acid (H_2SO_4), ammonium nitrate (NH_4NO_3), and nitric acid (HNO_3). These acids descend from the atmosphere with precipitation and affect the alkalinity of water bodies, forests and soils, wildlife and wildlife habitat, and degrade civil infrastructure.

- NO_x and volatile organic compounds (VOCs) react in sunlight and stagnant air to produce ground-level ozone (O_3). Ozone is a highly reactive gas that can cause asthma symptoms and premature mortality, decrease crop productivity, and degrade synthetic materials (such as rubber, paints, dyes, and textiles.)

- Secondary particulate matter (PM) is formed from sulphur oxides (SO_x), NO_x, and ammonia (NH_3). Many studies have linked PM to respiratory illness and heart disease.

- Smog is formed from O_3 and PM. Smog occurs throughout the year. In the summer, O_3 has a more significant effect, while PM contributes primarily to winter smog. Smog results increased hospital visits, hundreds of lost days of work, and thousands of premature deaths across Canada every year. Smog also affects vegetation, civil infrastructure, and visibility.

The major GHGs sourced from the heavy trucking are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The atmospheric lifetime and "heat-trapping potential" of GHGs are not equal. The term global warming potential (GWP) refers to the ability of each GHG to trap heat relative to CO_2. CH_4 and N_2O have GWPs of 21 and 310, respectively. Carbon dioxide equivalents (CO_2e) refer to the amount of CO_2 that would be emitted to have a similar warming effect for a given GHG. This is calculated by multiplying the gas emitted by its GWP. For example, one tonne of N_2O would be equivalent to 310 tonnes of CO_2e (Environment Canada, 2010b).

- Natural Resources Canada data from 1990 to 2007 reveal that GHG emissions by heavy trucks have increased by 161 percent (2008b). Figure 2 shows trends in truck freight GHG emissions, as mega-tonnes (Mt) of CO_2e, and truck freight activity from 1990 to 2007. CO_2e are a quantitative measure that describes the equivalent amount of CO_2 for a given GHG.

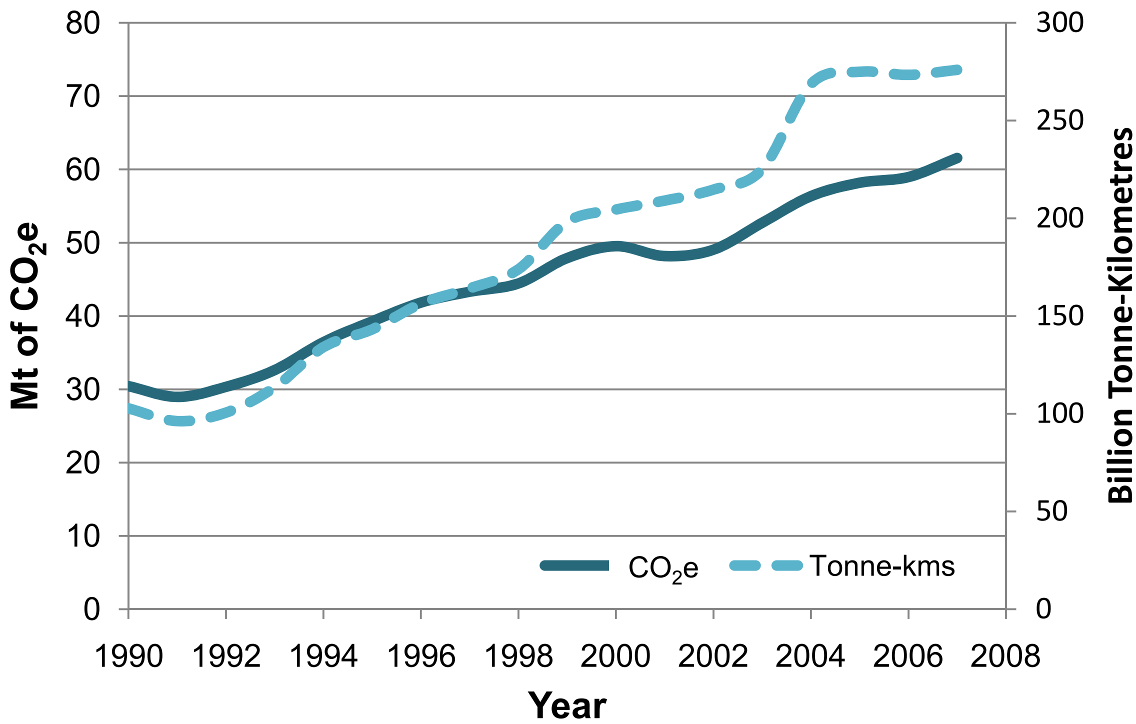


Figure 2: CO_2e Emissions and Road Freight Activity from 1990 to 2007

Source: Created by T. Baumgartner based on data from Natural Resources Canada (2008b)
Note: CO_2e describe the equivalent amount of CO_2 that would be emitted to have a similar global warming effect for a given GHG.

- Brodrick et al. (2004) test the effect of vehicle weight on emissions from a heavy-duty diesel truck. They analyze the emissions of NO_x, CO, and HC at various speeds and through different acceleration and deceleration cycles. The weight of the vehicle is tested at "half" (52,000 pounds) and "full" (80,000 pounds) (p. 121). The increase in weight "caused a greater than 40 percent increase in NO_x emission" (p. 125). They also determine that there is "no pattern" relating vehicle weight to CO emissions (p. 123) and HC emissions are not affected by the weight increase.

- Gajendran and Clark (2003) evaluate the effect of vehicle operating weight on diesel emissions. They conclude that "the data suggest that a weight increase of X% will result in a NO_x increase of about X/2% in most cases" (p. 4317). They also find that weight had little effect on CO emissions during steady-state operation, but did have a "considerable" effect during transient operation (p. 4317).

2.4 HEAVY TRUCK EFFICIENCY METRICS

- Leone (2009) reports that Wal-Mart has developed its own fuel efficiency metric: miles travelled per "case" of freight delivered. The company used this metric to identify fuel efficiency improvements of 38 percent from 2005 to 2008. In 2008, the company reduced truck travel by 87 million miles while it delivered 160,000 more cases than in 2007 (p. 27). Bennett (2009) defines Wal-Mart's "case" metric as a "carton or cardboard box containing some number of individual selling units, which could range from bottles of shampoo to a television set." There is no standardized size or weight for these cases (p. 12).

- Woodrooffe et al. (2009) refer to a report by the Organization for Economic Co-Operation and Development International Transport Forum (OECD/ITF) Transport Research Committee on international performance benchmarking of truck productivity (in terms of mass and volume of freight), efficiency, and emissions. A total of 40 truck configurations are analyzed from Australia, Belgium, Canada, Denmark, Germany, Mexico, the Netherlands, South Africa, the United Kingdom, and the United States. The cargo mass and volume are determined and vehicles are classified as one of three categories: workhorse, higher capacity, or very high capacity. The GVW and vehicle length properties for these categories and some examples of Manitoban configurations that fall into each category are shown in Table 3.

Table 3: Truck Productivity Classification

Classification	Properties	Manitoba Fleet Example	
		Vehicle Type	**Size & Weight**
Workhorse	Length < 22 metres GVW < 50 tonnes	Five-Axle Tractor Semitrailer	Length: 23 metres GVW: 39.5 tonnes
Higher Capacity	Length < 30 metres GVW < 70 tonnes	B-Train	Length: 25 metres GVW: 62.5 tonnes
Very High Capacity	Length > 30 metres GVW > 52 tonnes	Turnpike Double	Length: 41.0 metres GVW: 62.5 tonnes

Source: Woodrooffe et al. (2009)

The Canadian Turnpike Double yields the highest payload volume efficiency (in units of cargo cubic metres per tonne GVW) of the benchmarked heavy vehicles in the study. This vehicle also exhibits superior performance relative to other Canadian heavy trucks in terms of a new fuel efficiency metric, cargo mass volume by energy consumption, measured in units of cargo cubic-metre-tonne-kilometres per kilowatt-hour.

This study estimates the amount of CO_2 produced per kilowatt-hour from the following:

- Diesel fuel consumption rate for trucks: 200 grams per kilowatt-hour (assuming 50 percent efficiency).
- Density of diesel fuel: 850 grams per litre.
- CO_2 produced by diesel fuel: 2,668 grams per litre.

The authors conclude that fuel consumption and emissions are measures of resources consumed to move a vehicle, while fuel efficiency describes the resources consumed to accomplish a specific freight task. Therefore, fuel efficiency, as determined by the volume and mass of cargo transported is the preferred performance metric.

- McKinnon (2008) describes energy related key performance indicators (KPIs), as used in the United Kingdom, to provide a methodology to estimate carbon emissions. KPIs may consist of fuel efficiency, freight volume, freight weight, and the extent of empty operations. Certain parameters, such as vehicle utilization and fuel efficiency, can be combined into single metrics, such as fuel consumed per pallet-kilometre or tonne-kilometre.

- Bertram et al. (2008) estimate that the U.S. truck fleet efficiency improved from 1982 to 2002 as the fleet shifted from lighter trucks to heavier and more efficient trucks. This resulted in a 21 percent system-wide reduction in the gallons of fuel consumed per cargo ton-mile.

- Tunnel (2008) models energy use and emissions of higher productivity vehicles (HPVs). HPVs are longer and heavier trucks than the common five-axle tractor semitrailer. The author identifies GVW and engine size as the principal factors for determining heavy vehicle fuel consumption. Fuel efficiency is evaluated as ton-miles per gallon of diesel fuel. Fuel efficiency may be improved for cube-out scenarios through increases in vehicle length or a mix of vehicle length and GVW. Turnpikes are classified as an HPV.

  Turnpikes in the United States consist of two 48-foot trailers instead of two 53-foot trailers. The Turnpikes are found to have fuel efficiency savings (measured in ton-miles per gallon) of 33 percent over the five-axle tractor semitrailer for a weight-limited (GVW of 140,000 pounds) scenario, and 39 percent for a cube-limited scenario (GVW of 120,000 pounds).

- Malzer (2005) reveals that heavy truck fuel use is more sensitive to increases in truck kilometres of travel (TKT) than increases in GVW (shown in Figure 3). Therefore, in order to reduce fuel consumption and emissions of heavy trucks, efforts should be targeted towards reducing TKT.

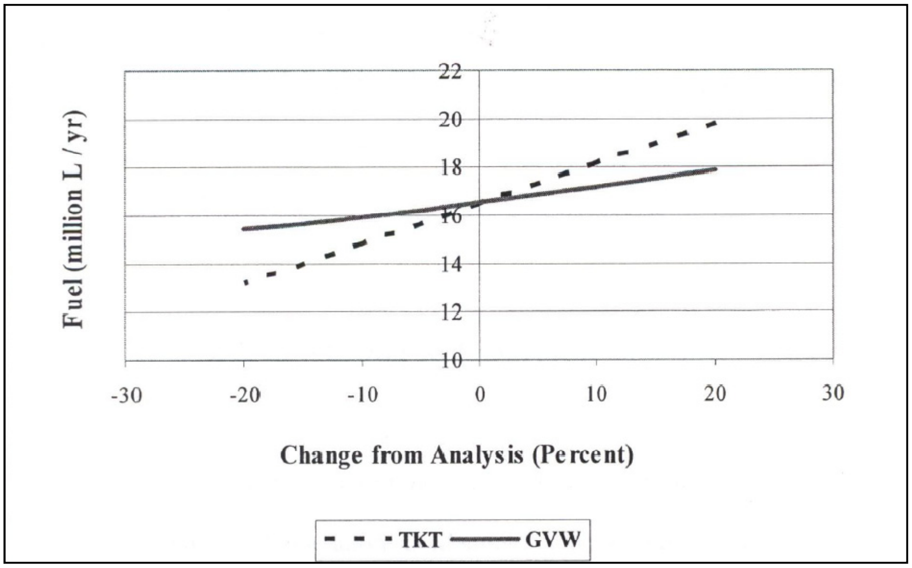


Figure 3: Sensitivity of Fuel Use to Changes in TKT and GVW

Source: © Malzer 2005. Used with permission.

- McKinnon (2005) considers the effect of an increase to the maximum GVW implemented in Britain in February 2001. He analyzes the benefits of the weight increase and finds the estimated savings shown in Table 4. From these estimates, he states that "the increase in maximum truck weight has yielded significant economic and environmental benefits" (p. 93). The author also finds that as road weight limits increase, larger proportions of loads cube-out before they weigh-out. The long term decline in road freight cargo densities means that a greater economic and environmental benefit results from increasing vehicle size rather than weight.

Table 4: Estimated Savings from the Increase in Maximum Truck Weight to 44 Tonnes

	2001	2002	2003
Reduction in annual truck-kilometres (million)	53	104	134
Savings in vehicle operating costs (£million) 2004 prices	44	85	110
Fuel savings (million litres) (average 0.37 litres/km or 7.5 mpg)	20.1	39.1	50.6
Reduction in emissions (tonnes)			
Carbon dioxide	53,800	104,800	135,700
Nitrogen oxide	351	684	884
Particulates (PM_{10})	12.5	24.4	31.5

Source: Recreated from © McKinnon 2005. Used with permission.

2.5 TECHNOLOGIES AND STRATEGIES TO REDUCE RESOURCE USE

This section summarizes literature findings regarding the technologies and strategies for reducing resource use, in terms of fuel consumption and emissions, of heavy trucks. It specifically addresses aerodynamic drag, rolling resistance, tare weight, idling, speed, and driver training.

2.5.1 Aerodynamic Drag

A truck's movement is opposed by wind resistance, which increases exponentially with speed requiring more energy to overcome the force. Aerodynamic devices can be designed into tractor semitrailers and/or attached to the vehicle to reduce the surface area of the vehicle that contacts the air when the vehicle is in motion. There are four main areas of drag on a tractor-trailer combination identified in the literature: the front of the tractor, the tractor-trailer gap, the undercarriage, and the rear of the trailer (Council of Energy Ministers, 2009).

- Cooper et al. (2009) model advanced aerodynamic drag and rolling resistance improvements that reduce the drag by 38 percent and rolling resistance by 34 percent. This results in fuel savings of about 25 percent. Applying these improvements to a U.S. Turnpike Double configuration at 140,000 pounds would result in similar fuel consumption as a baseline five-axle tractor semitrailer operating at 80,000 pounds. This information has only been modelled and would require a complete redesign of the truck-trailer combination to achieve a 38 percent reduction in aerodynamic drag.

- The Council of Energy Ministers (2009) evaluates various tractor and trailer aerodynamic devices. Cab-roof fairings and adjustable cab roof deflectors can be added to the tractor to reduce fuel consumption by six to eight percent and two to four percent, respectively. Trailer side fairings and rear fairings can reduce fuel consumption by four to seven percent and at least one percent, respectively. Aerodynamic devices used to reduce fuel consumption and emissions vary between different trailer body types (e.g., flatbeds, van trailers, and others).

  The authors indicate that a major truckload carrier has tested trailer side skirts on 1,000 of its 53-foot van trailers on both Turnpike Doubles and five-axle tractor semitrailers in Canada and the mainland United States. The company found that these technologies generated fuel savings and emissions reductions between four and five percent. In addition, drivers identified: (1) a considerable reduction in water and snow spray during wet and snowy road conditions; (2) less build up of ice and snow underneath the trailers; and (3) increased stability on trailers with side skirts in cross-wind conditions.

- Transport Canada (2009) describes road tests of aerodynamic fairings conducted as part of its ecoFREIGHT program. Carriers that tested aerodynamic fairings on the underside of the trailer experienced fuel savings averaging 6.4 percent. The three carriers that tested these technologies for Transport Canada found that for the 57 trailers tested, they saved a total of 7,768 litres of fuel per year, which translates into $7,768 in fuel costs savings annually (assuming one dollar per litre). They also reduced GHG emissions by about 212 tonnes per year. The fairings cost $2,450 and have a payback period of 1.2 to 2.2 years.

- Anair (2008) identifies that: (1) trailers tend to accrue less mileage than tractors and therefore, investments on trailer aerodynamics can be paid for over longer periods of time; (2) manufacturers still sell classic tractors (with a long nose, flat bumper, low roof, and exposed air cleaners, fuel tanks and exhaust stacks) despite the production of aerodynamic designs, which can reduce fuel consumption by as much as 15 percent; and (3) tractors that either pull different trailers on a trip by trip basis or have short-term or split trailer ownership do not generate consistent economic incentives to invest in trailer aerodynamic devices.

- Frey and Kuo (2007) analyze pneumatic blowing as an advanced technological method to reduce aerodynamic drag. Pneumatic blowing has been used on aircraft to reduce after-end aerodynamic drag and increase stability by blowing air from slots at the rear of the trailer. Some tractor semitrailer properties, such as the size of the gap between the tractor and trailer, can hinder the effectiveness of the system. If used in combination with aerodynamic devices that close the tractor-trailer gap, the benefits are not cumulative and may not justify the cost of the pneumatic blowing. The system is a high-technology application and can be costly. Estimates of potential savings in energy use and GHG emissions are about 2.2 percent.

- Leuschen and Cooper (2006) test several tractor technologies to reduce aerodynamic drag in a wind tunnel. They find that the combination of a standard cab-roof fairing, cab side extenders, and aerodynamic fairings on the fuel tanks could generate a two percent fuel consumption savings. Trailer technologies such as side skirts/belly fairings, tractor/trailer gap fairings and boat tails can save 6,670 litres of diesel for a single truck operating at 100 kilometres per hour over 130,000 kilometres.

2.5.2 Rolling Resistance

Rolling resistance is produced from overcoming tire deformation as the vehicle moves along the pavement under the weight of the truck. The energy utilized to overcome rolling resistance is directly proportional to the speed and mass of the vehicle (Saricks et al., 2007).

- Franzese et al. (2009) conduct a road test to compare the fuel efficiency of trucks with new generation wide-based single tires (NGWBSTs) to trucks with conventional dual tires. The experiment revealed a fuel efficiency improvement of six percent when either the tractor or trailer was equipped with NGWBSTs. Fuel efficiency improvements of up to nine percent were measured if both the tractor and trailer were equipped with NGWBSTs.

- Transport Canada (2009) reports on a nitrogen tire inflation field test conducted by Harris Transport Ltd. The use of nitrogen to inflate tires for 64 percent of their fleet yielded four to six percent in diesel fuel savings. Since tire rubber is less permeable to nitrogen than it is to air, nitrogen is more effective for maintaining tire inflation and increases tire tread life by approximately 85 percent.

- Frey and Kuo (2007) estimate reductions in GHG emissions from ATI systems, wide-based tires, low rolling resistance tires, and pneumatic blowing as 0.6, 2.0, 2.8, and 0.5 percent, respectively.

- Ogburn and Ramroth (2007) evaluate rolling resistance savings in new low rolling resistance tires and wide-based tires. They find that new low rolling resistance tires can reduce fuel consumption by four percent. The wide-based (super-single) tires can replace dual tires on tractors and trailers (except on the steering axle). The benefits of these tires reside in requiring only one rim (rather than two for conventional dual tires) and result in additional weight savings. Super singles can provide four to six percent savings in fuel consumption. Saricks et al. (2007) estimate fuel economy savings from low rolling resistance tires to be approximately three percent. The authors also find that the use of pneumatic blowing to provide lift underneath the semitrailer axles improves fuel economy by 1.2 percent. However, there are concerns with safety, road dust, and dislodgement of particles from the road surface associated with this application of the technology.

- Ang-Olson and Schroeer (2002) evaluate energy savings from tire design and maintenance perspectives. Wide-based tires have been available since the 1980s, but have received little market penetration. In North America, drivers have been concerned that the potential failure of one tire would leave them stranded, whereas dual tires provide redundancy. Early versions of wide-based tires exceeded several American state width laws and are still believed to be illegal by fleet managers.

Current models are wider than early versions and are legal throughout the United States.

Proper tire inflation increases tire tread life and reduces rolling resistance caused by under inflation. A drop in tire pressure by 10 psi will increase rolling resistance by about two percent and fuel consumption by 0.5 to one percent. ATI systems can eliminate tire under inflation. They can further reduce tire failure related emergencies and the time spent on periodic tire pressure inspections. ATI systems consist of pressure sensors and either a compressor mounted on the wheel hub that is charged by the wheel's rotation or a central compressed air supply that is powered from the braking system.

2.5.3 Tare Weight

- Cooper et al. (2009) find that fuel savings and emissions reductions generated by decreasing vehicle tare weight amount to 0.5 percent per 1,000 pounds of mass reduction.

- Ang-Olson and Schroeer (2002) indicate that tractor and trailer weight can be reduced by purchasing lightweight materials and eliminating unnecessary components. Some options include aluminum wheels, axle hubs, and tractor and trailer frames. For cube-out operations (most long haul) this yields savings in fuel consumption and emissions. For weigh-out freight this can increase cargo capacity and reduce fuel consumption per tonne-kilometre. Weigh-out freight tends to require more durable components especially for flat deck and tanker trailers. Aluminum components are utilized for refrigerated goods as aluminum resists rust and frozen goods are typically heavy loads.

2.5.4 Idling

- Groupe Énerstat Inc. (2009) indicates that a typical intercity truck in North America consumes 6,000 litres of diesel fuel and emits over 21 tonnes of CO_2, 120 kilograms of NO_x, and 21 kilograms of CO emissions per year while idling. Most of this consumption occurs during winter months. The authors find that in-cab climate control devices reduce idling time by six to 10 hours per day and have a payback period of 12 to 18 months. These devices reduce the diesel fuel consumed while idling by 90 percent and reduce emissions by 16,000 kilograms CO_2 equivalents per year.

- Mechron Power Systems (2009) conducts field tests on auxiliary power units (APUs), which are used to power in-cab climate control systems and electronic devices for sleeper cabs. APUs utilize diesel fuel more efficiently than an idling engine. They conserve 2,400 litres of diesel fuel per truck per year and reduce CO_2 emissions by 6.3 tonnes.

- Ogburn and Ramroth (2007) analyze a diesel-electric and a battery-electric APU for fuel and CO_2e savings. They find that the diesel-electric and battery-electric APUs reduce fuel consumption during idling by 80 percent and 90 percent, respectively.

- Montufar and Regehr (2004) cite a study by Stodolsky et al. (2000), where they analyze technology options to reduce the fuel consumption of idling trucks. The report states that “a typical intercity tractor-trailer idles an estimated 1,830 [hours per year] when parked overnight at truck stops", and that "long-haul trucks idling overnight consume more than 838 million gallons (20 million barrels) of fuel annually". The report presents truck stop electrification (TSE) as one "fuel-efficient" alternative to truck idling. Drawbacks to TSE include: (1) a limited choice of overnight TSE locations; (2) the requirement of separate sleeper air conditioner and electrically powered heater; and (3) the requirement of infrastructure at the truck stop. At the time of their study, TSE was not a commercially available option.

Montufar and Regehr (2004) also cite a study prepared for Niagara Mohawk Power Corporation by ANTARES Group Incorporated (2001), which identifies the following contributing factors to the potential need for TSE installation:

- In the U.S., current rest area, service area, and truck stop parking areas are "insufficient for today's long-haul truck volume". The current national shortage (estimated at almost 100 percent) "provides opportunity to put TSE into new as well as expanded truck parking and commercial truck stop facilities".

- As of December 2000, 15 states and the District of Columbia had enacted new anti-idling legislation that places limits on the amount of time a truck or bus can idle. "These laws, if enforced, would compel sleeper cab trucks on layover to use either on-board power, which doesn't necessarily reduce noise or emissions, or shore power/TSE to serve on-board loads". The states with anti-idling laws according to this report are: California, Colorado, Connecticut, District of Columbia, Hawaii, Illinois, Maryland, Montana, Nevada, New Hampshire, New Jersey, New Mexico, New York, Texas (pending), and Virginia.

- Federal (U.S.) drivers hours of service regulations “increase required length and frequency of driver rest periods.” This change “will potentially increase truck idling and, in turn, the potential market for shore power and TSE service”.

- Engine idling releases exhaust emissions to the air. The report quotes estimates that a single long-haul truck idling for 1,890 hours per year emits 21,000 pounds of carbon dioxide, 390 pounds of carbon monoxide, and 225 pounds of nitrogen oxides.

- “Truck engine idling has safety impacts in the sleep lost by truck drivers due to noise and high localized levels of CO”.

- “If present operating trends continue, even with in-place anti-idling laws, sleeper cab truck idling will increase, not decrease, as heavy truck vehicle-miles-of-travel increase”.

- “All Class 8 sleeper cab [original equipment manufacturers–OEM] now offer shore power as an option,” and customized retrofitting kits are available.

- Costlow (2004) cites a study by Argonne National Laboratory reporting that a typical heavy-duty freight-hauling truck idles an average of six hours per day or about 1,818 hours per year. The author refers to studies conducted by the Edison Electric Institute and the Argonne National Laboratory which show that idling a truck engine for 2,500 hours annually is the equivalent of 200,000 extra miles of engine wear, burning 3,750 gallons of diesel fuel, and increasing operating costs between US$4,000 and US$7,000 per truck per year.

- Perrot et al. (2004) report that “the average heavy-duty tractor consumes approximately one gallon of diesel fuel for each hour spent idling”, and that the total cost of idling (including service, maintenance, repairs, and fuel) is over $2.50 per hour of idling.

- The U.S. Environmental Protection Agency (2003) issued a technical bulletin that lists some benefits of using truck stop electrification. The bulletin states that the “use of truck stop electrification can reduce emissions by 90 percent and save 100 percent of the diesel fuel for the time spent idling.” It also indicates that the “fuel savings per year will amount to $3,240 per truck parking space.”

2.5.5 Speed

Two factors relating to vehicle speed influence fuel consumption: mechanical forces on the engine and drive train at lower speeds, and aerodynamic drag at higher speeds (Ray Barton Associates, Ltd., 2007). Speeds can be reduced for heavy duty fleets by speed governors installed in the tractor or by driver training coupled with incentives programs.

- Ray Barton Associates, Ltd. (2007) investigates mandating speed limiters (speed governors) in the province of Ontario. This mandate would affect all commercial motor vehicles operating in and through the province with a manufacturer’s GVW rating above 11,000 kilograms. The study estimates annual fuel savings of 228.6 million litres, which translates to 1.4 percent of total diesel fuel consumed by road vehicles in 2006. The direct relationship between fuel consumption and GHG emissions leads to GHG emissions reductions of approximately 0.64 megatonnes.

- Ang-Olson and Schroeer (2002) estimate fuel savings from reducing speed for intercity travel, which represents about 90 percent of long haul trips. A speed reduction from 70 mph to 65 mph would save 970 gallons per year (6.0 percent), and a speed reduction from 65 mph to 60 mph would reduce fuel use by 1,228 gallons per year (7.6 percent).

- Taylor (2001) estimates that fuel and emissions reductions generated by controlling Canadian truck speeds at 105 kilometres per hour or 90 kilometres per hour would yield savings of one and four percent, respectively.

2.5.6 Driver Training

- The National Research Council (2010) identify driver training is a relatively small investment and “appears” to be highly cost-effective in terms of reducing fuel consumption. Driver training is expected to be more effective for heavy loads and urban drive cycles. For example, opportunities for smoother breaking and acceleration would occur more frequently in urban areas than on rural highways in free-flow highway conditions.

- Ang-Olson and Schroeer (2002) list the following behavioural strategies used to improve fuel use: idle time reduction, speed limiting, adjustment of shifting technique, modification of acceleration practice, route choice, accessory load reduction, and decreasing the number of stops. These strategies are encouraged through programs designed to monitor and evaluate driver behaviour and provide incentives for drivers to reduce fuel consumption. The authors estimate that better shifting, acceleration, and route choice alone can yield at least four percent fuel savings.

- Taylor (2001) states that fuel consumption varies by up to five percent for different drivers operating under the same prescribed driving scenario. Recently developed power train systems are less sensitive to driver errors; in addition, real-time driver monitoring allows fleets to maintain a controlled operational envelope.

2.6 SUMMARY

The literature review reveals the following:

- The primary pollutants emitted by diesel internal-combustion engines are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), sulphur oxides (SO_x), hydrocarbons (HC), and methane (CH_4). These pollutants create greenhouse gases (GHGs), are detrimental to human health, affect the health of natural systems, and contribute to infrastructure deterioration. In Canada, GHG emissions by heavy trucks have increased by 161 percent between 1990 and 2007.

- Trucks that carry larger payloads (in terms of weight and cube) are more efficient (per weight-distance or cube-distance) than smaller, lighter trucks. Therefore, the liberalization of truck size and weight limits has the potential to yield environmental benefits. Studies which focus specifically on Turnpikes indicate that these vehicles provide fuel consumption and emissions benefits relative to the vehicles they replace.

- The literature identifies the use of a variety of metrics for measuring fuel consumption and emissions performance by heavy trucks. Metrics that incorporate cargo weight and/or cube enable more realistic comparisons between different types of trucking operations.

- Aerodynamic devices can be designed into tractor semitrailers and/or attached to the vehicle. Specific technologies identified in the literature to reduce aerodynamic drag are: cab-roof fairings, cab roof deflectors, trailer side fairings, rear fairings, fuel tank fairings, tractor/trailer gap fairings, aerodynamic tractors, pneumatic blowing, and cab side extenders.

- Tire technologies to reduce rolling resistance include: (1) wide-based tires (or super singles), which can replace dual tires thereby reducing tare weight, engine load and fuel consumption; (2) low rolling resistance tires; and (3) improved tire inflation and monitoring with automatic tire inflation (ATI) systems and nitrogen inflation.

- Technological options for reducing tractor and trailer tare weight include aluminum wheels, axle hubs, and tractor and trailer frames.

- The implementation of auxiliary power units (APUs) and the development and use of truck stop electrification reduce the fuel consumed and emissions produced by idling trucks.

- Operating speeds can be reduced for heavy duty fleets by speed governors installed in the tractor or by driver training coupled with incentives programs.

- Strategies that reduce fuel consumption by targeting driver behaviour include: idle time reduction, speed limiting, adjustment of shifting technique, modification of acceleration practice, route choice, accessory load reduction, and decreasing the number of stops. New drive train technologies are less sensitive to driver errors; in addition, real-time driver monitoring allows fleets to maintain a controlled operational envelope.

3. CHARACTERIZATION OF THE TRANSPORTATION SYSTEM

This chapter characterizes aspects of the transportation system affecting heavy truck energy use and emissions. The transportation system is described in terms of: (1) the road network; (2) vehicle and operating characteristics; (3) technologies; and (4) emission regulations and initiatives.

3.1 CANADIAN PRAIRIE REGION TURNPIKE DOUBLE NETWORK

Alberta, Saskatchewan, and Manitoba routinely permit Turnpikes on all divided, rural highways. This research focuses on the rural, regional network where Turnpikes are permitted to operate. Currently, this network measures approximately 4,100 centreline-kilometres, serves a population base of about six million people, and consists of twinned primary highways that are largely uncongested. Figure 4 shows this network as of January 1, 2011.

- Alberta's Turnpike network is the largest of the three Prairie Provinces and consists of 2,200 centreline-kilometres (54 percent of the Region's total).
- Saskatchewan's Turnpike network measures 1,200 centreline-kilometres (29 percent of the Region's total).
- Manitoba's Turnpike network measures 700 centreline-kilometres (17 percent of the Region's total).

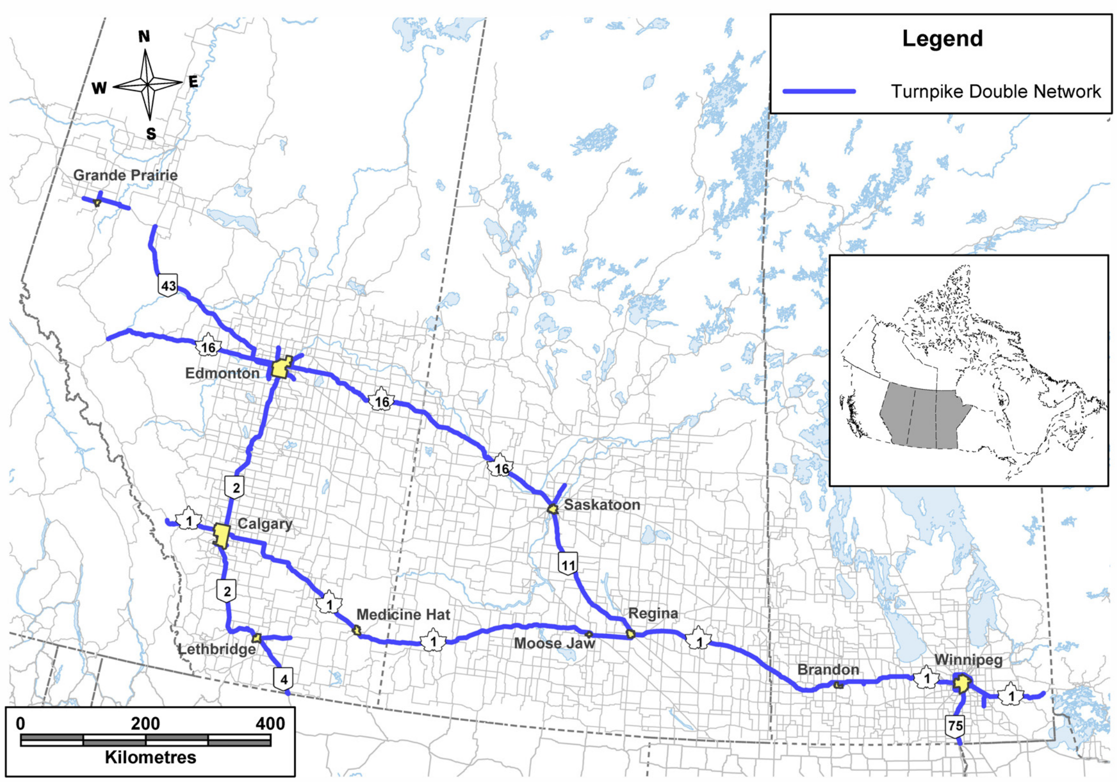


Figure 4: Canadian Prairie Region Turnpike Double Network

Note: Network measures 4,100 centreline-kilometres as of January 1, 2011

The Turnpike Double permitting policies in Alberta, Saskatchewan, and Manitoba have developed over the years to establish a directly interconnected network to facilitate regional operations. Regulatory prohibitions of Turnpike operations in British Columbia, northwest Ontario, and the United States, cause certain sections of the Prairie region's Turnpike Double network to be operationally impractical. This results in limited Turnpike traffic on highways leading out of the region. Currently, there is no Turnpike traffic crossing the international border, however, some carriers assemble Turnpikes from two northbound 3-S2s after crossing the Manitoba-U.S. border, and disassemble southbound Turnpikes into two 3-S2s prior to crossing the border.

3.2 HEAVY TRUCK EMISSIONS REGULATIONS AND INITIATIVES

Heavy truck emissions are regulated at the Federal government level in Canada. The regulations target the reduction of the detrimental effects of heavy truck emissions on human health and the environment. These regulations have been targeted towards motor vehicle and engine manufacturers and diesel fuel suppliers. New technologies produced by the manufacturers to meet emission regulations tend to come at a higher cost. Governments have developed initiatives for trucking companies to help finance new technologies and develop practices that target reducing emissions and fuel consumption.

3.2.1 Regulations to Reduce Truck Emissions

Motor vehicle and engine manufacturing in Canada and the U.S. are tightly integrated. This has enabled Canada to harmonize its vehicle emission regulations with that of the U.S. Environment Protection Agency (EPA) since 1988 (Department of Environment, 2003). Table 5 shows the maximum emission level standards for heavy duty diesel engines in units of pollutant mass per unit work. For comparison, regulations governing engine emissions in Mexico, the European Union, Japan, and Australia are also provided. As shown in the table, diesel engine manufacturers in Canada and the United States were required to reduce PM by 90 percent for 2007 engines. According to the Canadian Trucking Alliance (CTA, 2009), as of 2010, new engines must cut NO_x emissions by 95 percent from 2007 levels. These newer engines cost seven to 10 percent more than the previous models and have higher maintenance costs (CTA, 2009).

Table 5: Heavy Duty Engine Emission Regulations for North America, Europe, Japan and Australia

	Year in Effect	Regulation Name	NO_x	HC	CO	PM
			g/kWh			
Canada / U.S [a, 1]	2004	US04	-[b]	-[b,c]	20.8	0.13
	2007[d]	US07	0.27	0.19	20.8	0.013
Mexico [e, 2]	2008	US04/ EuroIV	3.5	0.46	1.5	0.02
European Union[2]	2005	Euro IV	3.5	0.46	1.5	0.02
	2008	Euro V	2.0	0.46	1.5	0.02
	2013	Euro VI	0.4	0.13	1.5	0.01
Japan [2]	2005[d]	JE05	2.0	0.17[c]	2.22	0.027
	2009		0.7	0.17[c]	2.22	0.01
Australia [e, 2]	2007	US04/ Euro IV/ JE05	3.5	0.46	20.8	0.13
	2010	US07/ Euro V/ JE05	2.0	0.46	20.8	0.02

Notes:
[a] Converted into units of g/kWh. Regulation set at g/bhp-hr (U.S.) and g/MJ (Canada).
[b] Regulation is set for NO_x + NMHC ≤ 3.2 g/MJ.
[c] Regulation is for non-methane hydrocarbons.
[d] Regulation for PM comes into full effect in 2007 and NO_x phased in from 2007 to 2010.
[e] Regulations and technology are adopted from another country. Values presented are the maximum value of the available regulations.
[f] Regulation comes into full effect at the end of 2005

Sources:
[1] Department of Environment (2003)
[2] Dieselnet (2010a)

The U.S. Environment Protection Agency (EPA) and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) (2010) have proposed the first program to reduce GHG emissions and fuel consumption for heavy duty vehicles. The goals of this program are to improve energy security and address climate change. The targeted GHG pollutants are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFC). The proposed standards would phase in to 2017 and target a seven to 20 percent reduction in CO_2 emissions and fuel consumption. The limits by EPA and NHTSA are summarized in Table 6. These limits are based on the type of power unit and roof height. The roof height dimensions are not identified in the proposed standard nor the rational for day cab and sleeper cab.

Table 6: Proposed 2017 U.S. CO_2 and Fuel Consumption Emission Standards

Cab Type	EPA Emission Standards (grams CO_2 per ton-mile)			NHTSA Fuel Consumption Standards (gallons per 1000 ton-mile)		
	Low Roof	Mid Roof	High Roof	Low Roof	Mid Roof	High Roof
Day Cab	78	78	86	7.7	7.7	8.5
Sleeper Cab	64	69	71	6.3	6.8	7.0

Source: U.S. EPA (2010)

Sulphur oxide emissions have also been controlled in Canada through the Diesel Fuel Regulation, which came into effect on January 1, 1998. This regulation sets the maximum sulphur content of diesel fuels at 500 ppm. The United States set the same level for diesel fuel in 1993. By June 1, 2006, the two countries regulated an ultra-low sulphur diesel fuel with a maximum of 15 ppm (Department of Environment, 2002). Table 7 summarizes diesel fuel sulphur content regulations in North America, the European Union, Japan, and Australia.

Table 7: Diesel Fuel Sulphur Content Regulations in North America, European Union, Japan and Australia

	Year of Regulation	Sulphur Content (ppm)
Canada	2006	15
United States	2006	15
Mexico	2009	15
European Union	2009	10
Japan	2007	10
Australia	2009	10

Source: Dieselnet (2010b)

3.2.2 Initiatives to Reduce Fuel Consumption and Emissions

The research identifies the following initiatives that are specifically directed at supporting reducing fuel consumption and emissions in the Canadian Prairie region: (1) FleetSmart; (2) SmartWay; (3) ecoFREIGHT; (4) Trucks of Tomorrow; and (5) GrEEEn Trucking.

3.2.2.1 FleetSmart

Natural Resources Canada's ecoENERGY for Fleets program introduces commercial vehicle fleets to energy efficient practices to reduce fuel consumption and emissions. FleetSmart is a component of the program that offers free information on energy efficient vehicles and business practices to reduce fleet operating costs, improve productivity, and increase competitiveness. FleetSmart offers two main workshops called SmartDriver and Fuel Management 101. These workshops focus on behaviours that can be modified and practices that can reduce fuel consumption. Targeting fuel consumption reduction also reduces business costs and GHG emissions (Natural Resources Canada, 2010).

ecoENERGY for Fleets, through its FleetSmart initiative, has funded research and case studies intended to identify technologies that can be adopted by carriers to reduce fuel consumption. This has emerged from a partnership with the U.S. Environment Protection Agency's (EPA) SmartWay program to test SmartWay certified technology such as aerodynamic devices and low rolling resistance tires to reduce heavy truck fuel consumption and emissions. SmartWay has also adopted FleetSmart's SmartDriver curriculum for use in the U.S. (Natural Resources Canada, 2010).

3.2.2.2 SmartWay

SmartWay is a branding program developed in 2004 to identify fuel efficient transportation options. The brand signifies a partnership between government, the private sector, and consumers to support these options. SmartWay offers information on emission ratings of vehicles and technologies and financing to support research and development of these technologies. SmartWay provides rankings to its members so that customers may purchase goods from carriers that are considered to have lower emissions impacts than their competitors (SmartWay, 2010).

3.2.2.3 ecoFREIGHT

Transport Canada's ecoFREIGHT has allocated research funding for motor carriers to test several GHG emission reduction technologies. These devices reduce emissions primarily by reducing fuel consumption. This program field tested technologies that reduce aerodynamic drag, rolling resistance, and idling. The effectiveness of energy and emissions reduction technologies in the trucking sector is dependent on the driver. Driver training and monitoring programs can achieve three to 20 percent fuel savings compared to driver behaviour before these programs are initiated (Transport Canada, 2009).

3.2.2.4 Trucks of Tomorrow

Climate Change Central is a private-public non-profit organization in Alberta established in 1999. They provide consumer rebate programs, demonstration projects, and educational outreach to encourage action on climate change in Alberta. They have established the Trucks of Tomorrow initiative which is a partnership with the Government of Alberta to help commercial vehicle operators adopt fuel consumption reducing technologies to cut their costs and reduce emissions. In 2010, the Province of Alberta has invested two million dollars over 18 months to provide rebates on technologies and provide education to maximize fleet performance. The program will provide 25 companies with a comprehensive fleet analysis, and four workshops of fuel efficiency will be held throughout Alberta (Climate Change Central, 2010).

3.2.2.5 GrEEEn Trucking

In 2009, the Manitoba Trucking Association partnered with Manitoba Infrastructure and Transportation (MIT), and the University of Manitoba Transport Institute (UMTI) to introduce the GrEEEn (Economically and Environmentally Efficient) Trucking incentive program. The program provides financial incentives to motor carriers to adopt GHG emission reduction technologies. They are required to provide a minimum $2,000 investment to be eligible for rebates ranging from 15 to 25 percent of the capital investment ($2,500 per unit maximum). The technologies consist of alternative power units (APUs), low rolling resistance tires, and tractor and trailer aerodynamic devices (Manitoba Trucking Association, 2009).

3.3 TECHNOLOGIES AND STRATEGIES USED BY CARRIERS

The literature reveals numerous technologies and strategies that reduce heavy truck fuel consumption and emissions. Other than engine related technologies, the technologies fall into these categories: those that reduce aerodynamic drag, reduce rolling resistance, reduce vehicle tare weight, reduce vehicle idling, and control speed.

3.3.1 Carrier Survey Questionnaire

A questionnaire was developed, from the findings in the literature search, to identify the use of technologies and practices to reduce fuel consumption and emissions. The questionnaire accompanied a survey to acquire fuel consumption data from the carriers. This is addressed in Section 4.1. Figure 5 summarizes the information requested by the questionnaire. The full questionnaire used is included in Appendix B.

1. Fleet size – number of tractors and trailers
2. Annual VKT for 2007 to 2009 for Turnpike Doubles and five-axle tractor semitrailers
3. Use of technologies to reduce energy consumption:
   - Aerodynamic devices
   - Automatic tire inflation systems
   - Nitrogen inflation
   - Wide-based tires
   - Low-weight aluminum wheels
   - Idle reduction technologies (e.g., APUs, cab heaters and coolers)
4. Use of technologies to reduce emissions:
   - Diesel particulate filters
   - Diesel oxidation catalyst
   - Urea-based selective catalytic reduction (2010 engine)
5. Reasons to reduce company's energy use and emissions
6. Speed reduction programs and speed governing
7. Use of driver training programs

Figure 5: Information Requested by Questionnaire

The companies that completed the questionnaire are based in the Prairie Provinces and operate throughout North America utilizing Turnpikes throughout the Canadian Prairie region. All companies specialize in the movement of general freight using dry and temperature controlled vans. These companies operate a combined fleet of 2,200 tractors and 6,000 trailers in North America. Table 8 lists the types of technologies adopted by the carriers surveyed as part of this research. They account for 127 million vehicle-kilometres of travel in the Canadian Prairie region and 365 million vehicle-kilometres of travel in North America in 2009. The surveyed companies had a combined growth in Turnpike VKT from 2007 to 2009 of 44 percent. Due to a confidentiality agreement, the number and names of the companies cannot be identified in this thesis document.

Table 8: Technologies Adopted by Surveyed Carriers

Technology	% of Fleet Equipped	
	Tractors (%)	Trailers (%)
Aerodynamic Devices	100	18
Automatic Tire Inflation System	0	< 1
Nitrogen Tire Inflation	6	1
Wide-Based Tires	1	< 1
Low-Weight Aluminum Wheels	79	56
Alternative Power Units	54	N/A
Cab Heaters and Coolers	26	N/A
Speed Governors	100	N/A

Notes: N/A – not applicable.
Carriers were surveyed throughout 2010.

Each of the carriers implements speed reduction practices as a matter of company policy through the installation of speed governors, and the development of driver training and monitoring programs. Speed limits are defined by company policy and the governed speeds for each company. Companies set speed limit policies between 95 and 105 kilometres per hour and set governors between 97 and 105 kilometres per hour.

3.3.2 Engine Technologies

In order to meet 2010 emission standards, truck manufacturers have been developing two principal technologies: advanced exhaust gas recirculation (EGR) and selective catalytic reduction (SCR). EGR technology was previously developed to meet emissions regulations for NO_x. Advanced EGR engines are now being developed to further reduce emissions and meet 2010 standards. EGR functions by returning the exhaust gas into the engine combustion chamber resulting in less combustible material and nitrogen from the air. This reduces the heat of the reaction and produces substantially less NO_x; however, it also results in lower fuel efficiency of the engine and increased PM, HC, and CO production (Leavitt, 2008). A diesel particulate filter (DPF) is used downstream to remove PM. The DPF requires the driver to routinely ‘regenerate’ the device by using a fuel burner to remove soot (Hao et al., 2009).

SCR utilizes an after treatment in a separate chamber to reduce NO_x emissions. This allows the engine to operate at higher temperatures, while initially increasing NO_x production. The exhaust stream is mixed with diesel exhaust fluid (DEF) that contains primarily water and urea as the active compound. The NO_x mixes with the urea solution over a catalyst to produce water vapour and nitrogen gas. A diesel particulate filter is also used to remove PM. This system produces less PM than EGR and the high heat of the engine allows for passive regeneration of the diesel filter. This means that the engine reduces the heat required to remove soot and does not require the driver to actively maintain the filter (Fancher, 2010 and Leavitt, 2008).

There are several concerns with the SCR technology (CTA, 2009 and Leavitt, 2008):

- Infrastructure to acquire urea is still in development.
- Urea freezes at - 11^{o}C and requires heated lines.
- The DEF tank and heated lines add tare weight.
- Purchasing diesel exhaust fluid adds to operating costs.
- Selective catalytic reduction technologies increase capital costs (by seven to 10 percent).
- Urea is used as a fertilizer for its high nitrogen concentration. It is considered a water pollutant causing eutrophication that can harm fish and fish habitat.

SCR and EGR are very different systems in terms of maintenance, operation, and cost. The majority of engine manufacturers in North America are producing SCR to meet 2010 emission standards.

3.4 VEHICLES AND OPERATING CHARACTERISTICS

The vehicles of interest to this research and their operating characteristics are evaluated for the network from weigh-in-motion (WIM) devices. In addition, on-site surveys were conducted at weigh scales on the Manitoba portion of the Turnpike Double Network to better understand the operation of 3-S2s and Turnpikes in the Province.

3.4.1 Weigh-In-Motion Data

WIM data were collected from 11 stations on the Turnpike Double network in 2009 to understand Turnpike operating characteristics in the region. These locations are shown in Figure 6.

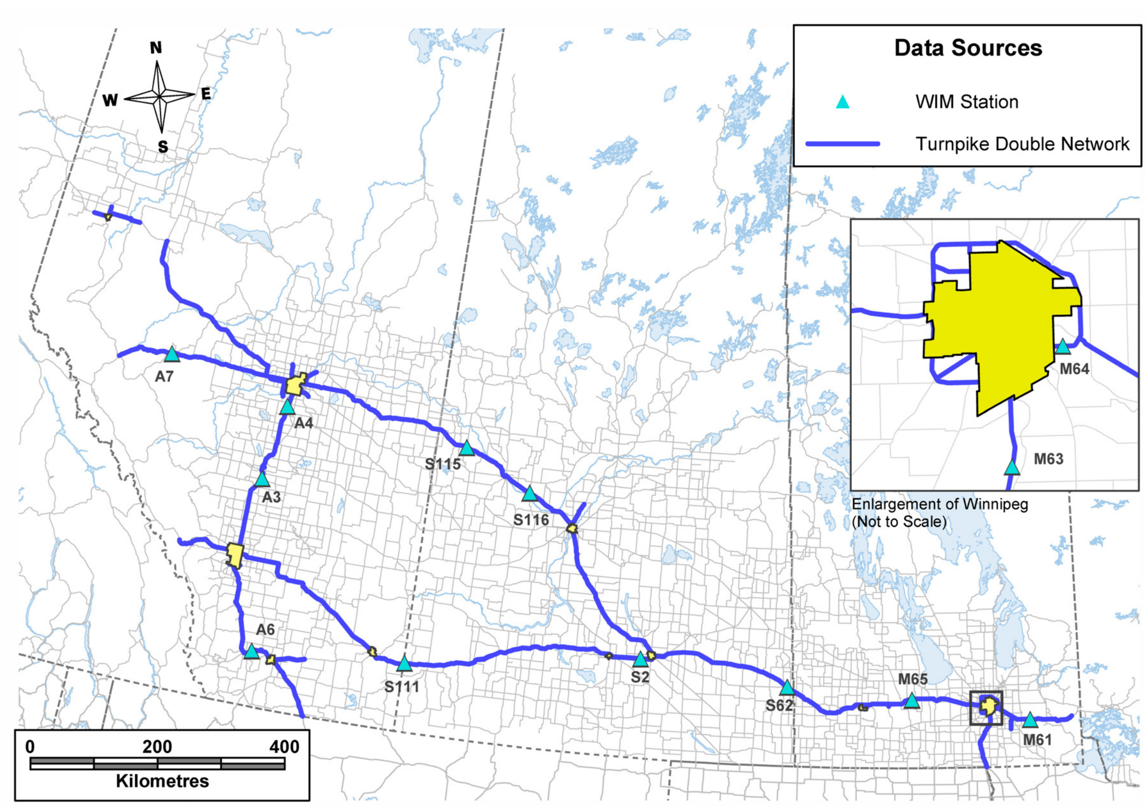


Figure 6: WIM Station and Weigh Scale Locations on Turnpike Double Network

Stations A3, A4, S111, S2, S62 and M65 are used to illustrate the temporal characteristics of Turnpikes for 2009 in the network. Station A3 and A4 are located in Alberta on Highway 2. The other stations analyzed occur on Highway 1 between Calgary and Winnipeg.

The WIM data are used to isolate Turnpikes in the vehicle fleet. Since the WIM data provides axle spreads, it can be used to classify specific vehicle type. This is done within a database environment using Structured Query Language (SQL). Turnpikes are usually grouped together with other multiple trailer trucks with seven or more axles. An algorithm developed by Regehr, et al. (2009) isolates and classifies Turnpikes (in addition to Rocky Mountain Doubles and Triple Trailer Trucks) based on the vehicle's wheelbase, number of axles, and axle spacing (from centre-to-centre distance between axles).

There are eleven Turnpike axle configurations that are permitted to operate in the Canadian Prairie region based on each Province's Turnpike Double permitting program. The detections of these vehicles by Prairie region WIM devices on the Turnpike network in 2009 are shown in Table 9.

As Table 9 shows, Saskatchewan accounts for 44 percent of the total Turnpike counts, Alberta accounts for 35 percent and Manitoba accounts for 21 percent. The most common Turnpike configuration is the 3-S2-4, which represents more than 72 percent of the Turnpike fleet. This is followed by the 3-S2-3, which comprises over 13 percent of the Turnpike configurations detected by WIM devices on the Prairie region network. The remaining three detected configurations represent less than one percent of the Turnpike fleet mix.

Table 9: Turnpike Double Configurations in Canadian Prairie Provinces at WIM Stations in 2009

Turnpike Double Configuration	Alberta	Saskatchewan	Manitoba	Total
3-S2-2	273	86	67	426
3-S2-3	14,474	9,667	2,956	27,097
3-S3-S2	32	2,577	1,232	3,841
3-S2-4	40,569	6,9498	36,216	146,283
3-S3-3	2,604	1,039	64	3,707
3-S2-4 (b)	1,606	552	45	2,203
3-S3-S3	7	91	30	128
3-S2-5	3,200	1,444	798	5,442
3-S3-4	2,873	222	18	3,113
3-S3-4 (b)	4,828	3,560	1,078	9,466
3-S3-5	966	279	0	1,245
Sample Size	**71,432**	**89,015**	**42,504**	**202,951**

Source: 2009 WIM data for Stations A3, A4, A6, A7, S2, S62, S111, S115, S116, M61, M63, M64, and M65

Note: (b) indicates an alternative axle arrangement for a given configuration number.

The total counts of Turnpikes at each of the WIM stations are summarized in Table 10. Station M65, located at MacGregor, Manitoba, experiences the highest volumes of Turnpikes. Figure 7 shows the annual average daily Turnpike volumes from 2005 to 2009 for station M65 at MacGregor. During this period, Turnpike volumes at the MacGregor station increased by 78 percent. The volume has grown significantly from 2007 to 2008 (by 31 percent), partly attributed to the completion of the divided highway section between Virden, MB and Moosomin, SK, which completed a link for Turnpike operations from Calgary, AB to Winnipeg, MB along the Trans Canada Highway (Highway 1). Further increases in Turnpike volumes from 2008 to 2009 (by 33 percent), are partially attributed to an economic recession. The trucking companies that provided data for this research indicated that operating Turnpikes became a necessity in order to remain competitive.

Table 10: Count of Turnpikes at WIM Stations

Station	Highway	Name	Direction	Count of Turnpike Doubles
A3	2	Red Deer	NB/SB	35,651
A4	2	Leduc VIS	NB/SB	30,744
A6	3	Fort McLeod	EB/WB	4,041
A7	16	Edson	EB/WB	996
S2	1	Grand Coulee	EB/WB	17,453
S62	1	Fleming	EB/WB	29,938
S111	1	Maple Creek	EB/WB	21,389
S115	16	Maidstone	EB/WB	10,158
S116	16	Maymont	EB/WB	10,077
M61	1	Brokenhead	EB/WB	150
M63	75	Glenlea	NB/SB	1,372
M64	100	Symington	EB/WB	357
M65	1	MacGregor	EB/WB	40,625
			Total:	**202,951**

Source: 2009 WIM data

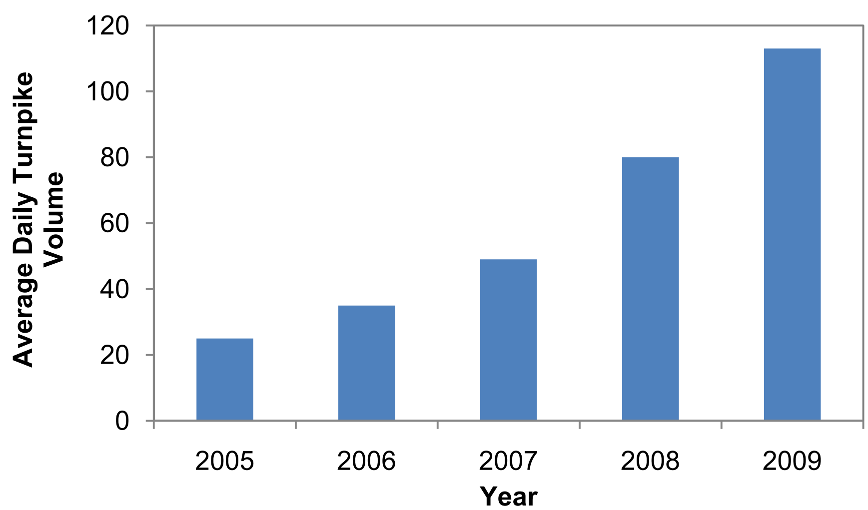


Figure 7: Annual Average Daily Turnpike Volume at MacGregor, MB from 2005 to 2009

Temporal distributions of time of day, day of week, and month are developed for stations A3, A4, S2, S62, S111, and M65 as they have large volumes of Turnpikes to estimate their average daily truck traffic (ADTT). Figure 8 shows stations A3 and A4 between Edmonton and Calgary on Highway 2. These stations experience similar temporal characteristics of Turnpikes with higher volumes between 19:00 and 23:00. Figure 9 shows stations S111 and S2 on Highway 1. S111 is located at near the Alberta-Saskatchewan border and experiences higher truck volumes between 21:00 and 02:00. Station S2 is located west of Regina and experiences outages in January and February resulting in low Turnpike volume proportions for those months. The station experiences higher Turnpike volumes around 02:00 to 06:00 and 18:00 to 19:00. Figure 10 shows stations S62 and M65 on Highway 1. Station S62 is located near the Saskatchewan-Manitoba border and counts higher Turnpike volumes for the hours of 00:00 to 01:00 and 21:00 to 23:00. Station M65 is located between Brandon and Winnipeg and has the largest number of Turnpike records of the eleven stations processed. It experiences higher Turnpike volumes around 13:00 to 14:00 and 20:00 to 23:00. M65 has a mix of WIM and automatic vehicle classification (AVC) devices. The AVC data is binned into the FHWA 13-vehicle classification scheme and, therefore, does not provide the axle spread data that are used to identify Turnpikes from WIM devices. The AVCs are located in the pass lanes and WIMs in the drive lanes. Since Turnpikes rarely travel in the pass lane, these volumes are considered negligible.

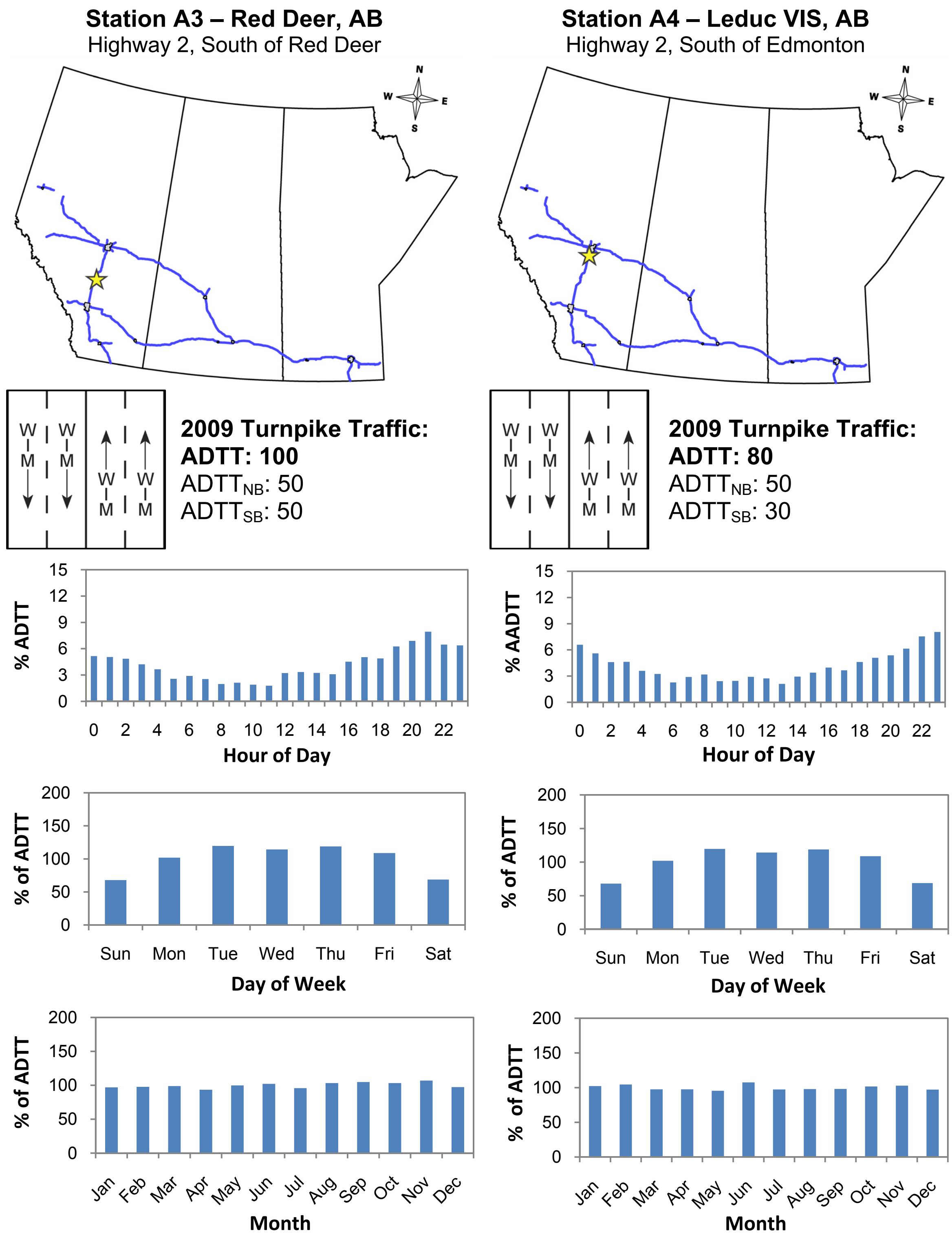


Figure 8: Temporal Distributions for Turnpike Doubles at Stations A3 and A4

Note: 2009 WIM Data

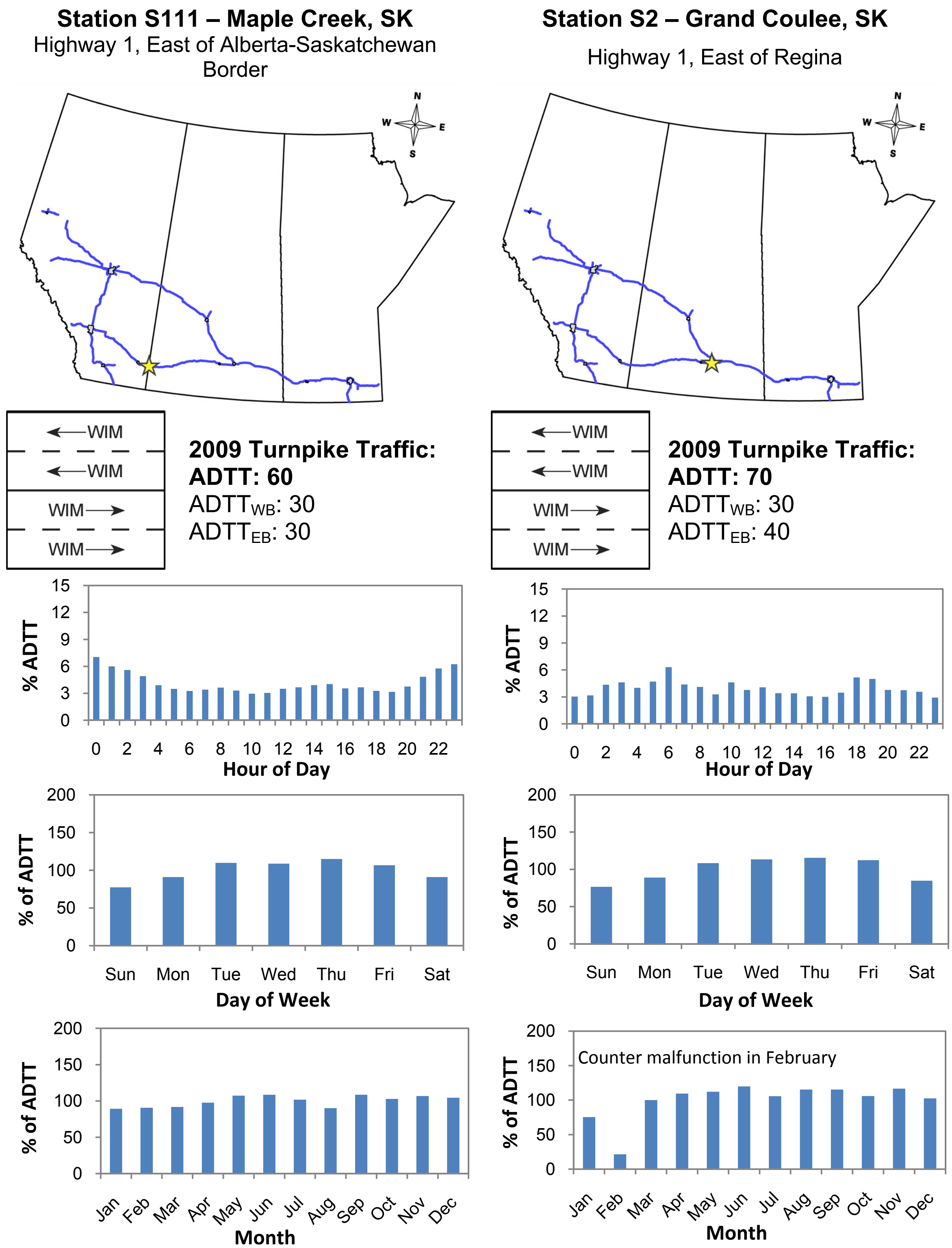
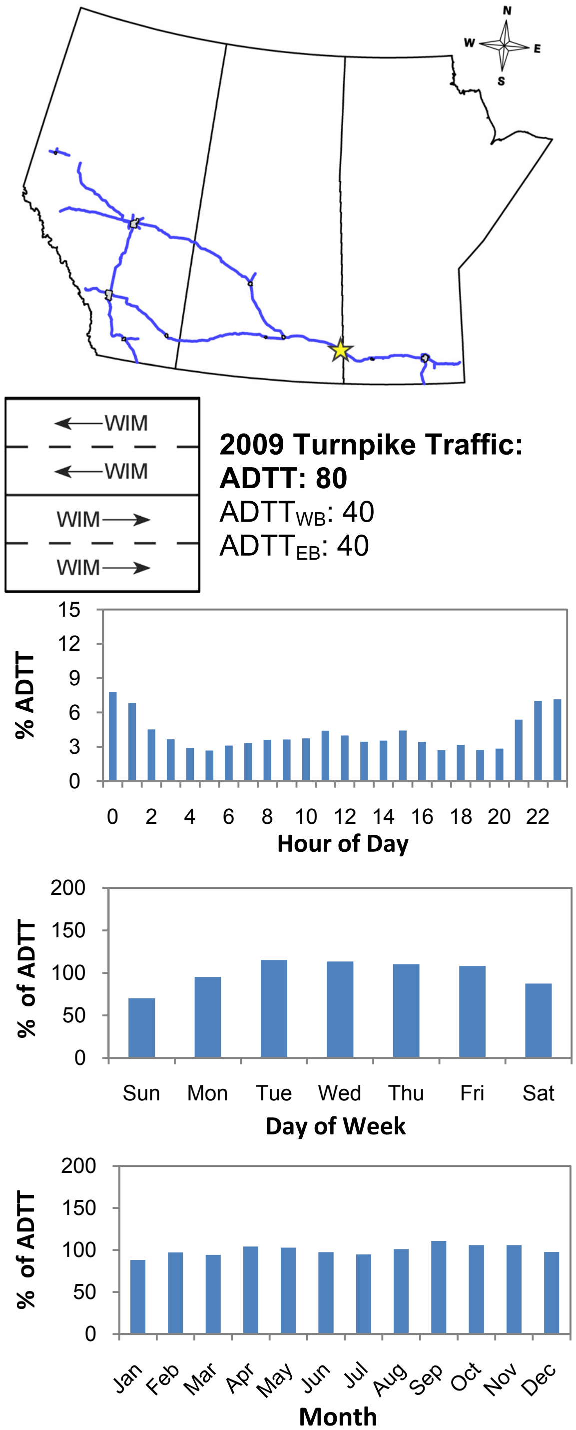


Figure 9: Temporal Distributions for Turnpike Doubles at Stations S111 and S2

Note: 2009 WIM Data

Station S62 – Fleming, SK
Highway 1, West of the Manitoba-Saskatchewan Border



Station M65 – MacGregor, MB
Highway 1, Between Brandon and Winnipeg

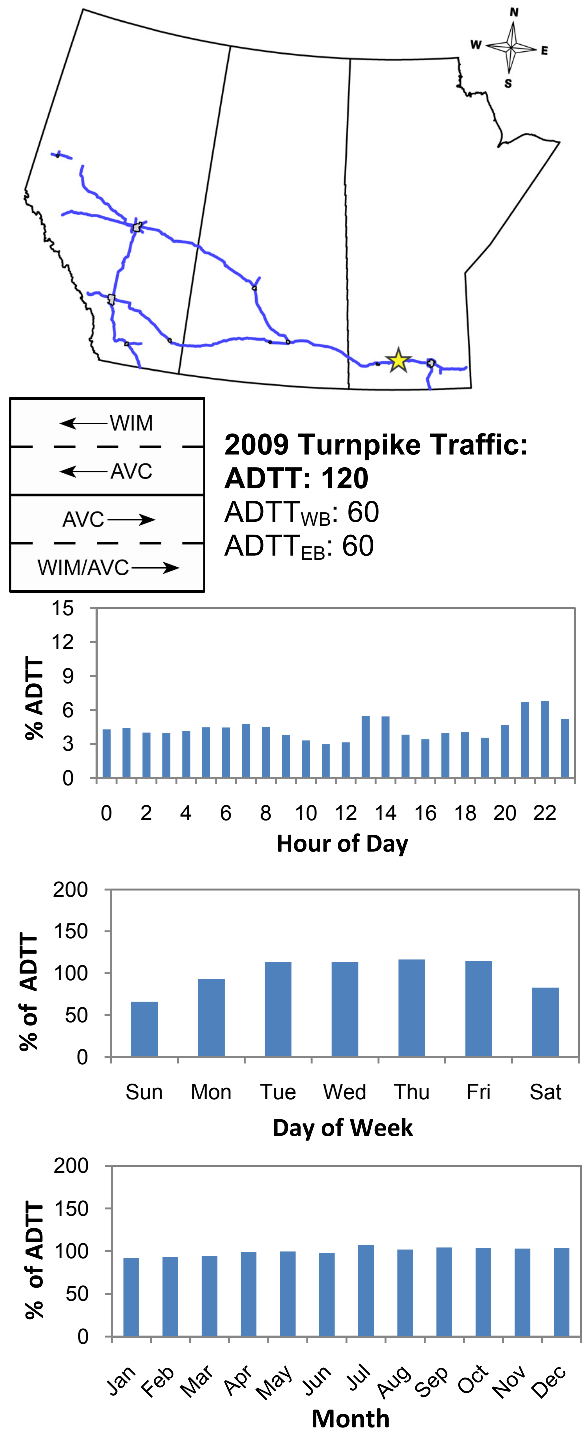


Figure 10: Temporal Distributions for Turnpike Doubles at Stations S62 and M65

Note: 2009 WIM Data

3.4.2 Weigh Scale Survey

Three weigh scale surveys were conducted to acquire data on static weights and body types of 3-S2s and Turnpikes operating in Manitoba. Since Turnpikes only have van body types (dry and refrigerated), it is necessary to estimate the proportions of 3-S2s with van body types for comparison and their static weights. To obtain these data, specialized surveys were conducted at three locations on Manitoba's Turnpike Double network. The surveys were conducted at the Headingley, Emerson, and West Hawk weigh scales for five working days in January and February 2010. The Headingley scale is located on PTH 1, 7.5 kilometres west of Winnipeg; the Emerson scale is located just north of the Canada-U.S. border on PTH 75; and the West Hawk scale is located on PTH 1 about one kilometre west of the Manitoba-Ontario border. These locations are shown in Figure 11.

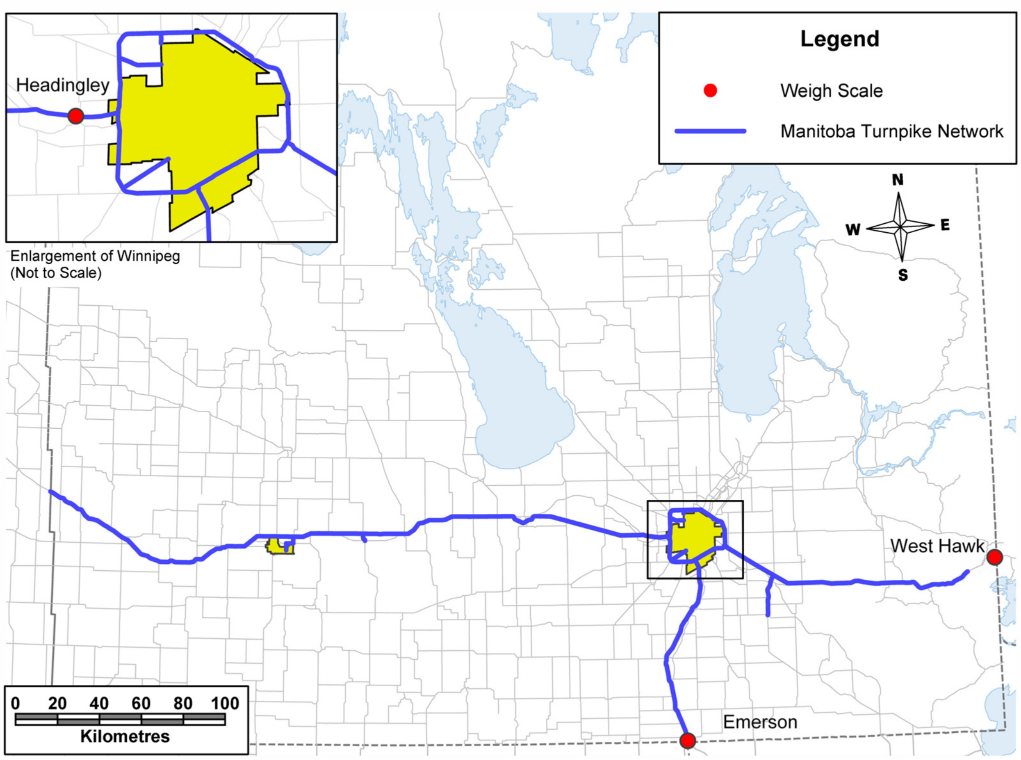


Figure 11: Weigh Scale Survey Locations

The Headingley weigh scale is located on a major link for Turnpike operations in the Canadian Prairie region. It experiences high volumes of inter- and intra-provincial truck traffic. The AADTT at this location was 2,280 in 2009. The scale is typically open 24 hours per day on weekdays, subject to availability of resources. The data collection at this scale began on Tuesday, January 26, 2010 at noon, and ended the following Tuesday, February 2, 2010 at noon. The hours of data collection by day of week at the scale are shown in Figure 12. Due to available resources from the Motor Carrier Division, data collection did not occur simultaneously in each direction at the weigh scale. More hours of observation occurred in the eastbound direction than the westbound. The truck fleet distributions at the Headingley scale by axle configuration and body type are shown in Appendix C.

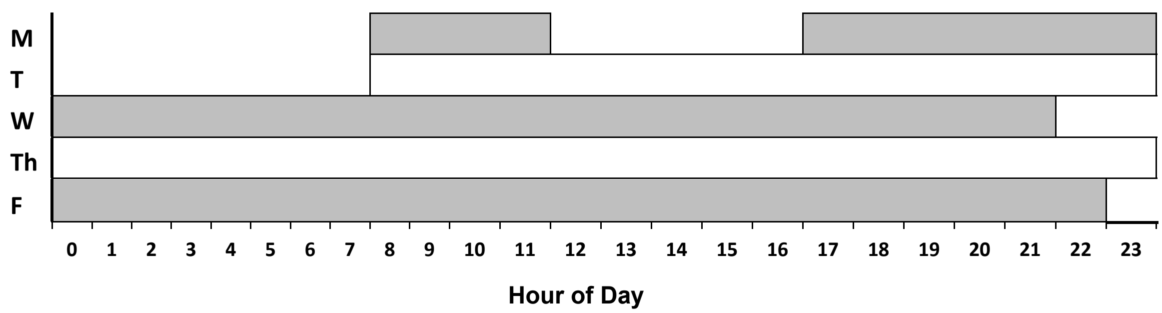


Figure 12: Data Collection Hours at the Headingley Weigh Scale

Notes: During the survey, the Headingley weigh scale was open 24 hours per day, Monday to Friday. Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

The Emerson weigh scale is located at Manitoba's most active trade border with the United States. Therefore, this scale is heavily influenced by the U.S. truck size and weight regulations since they are more restrictive than Manitoba's regulations. The AADTT at this location was 1,180 in 2008 (flooding in 2009 resulted in insufficient data to estimate AADTT at Emerson). The scale is typically open from 07:00 to 20:00. Data were collected from Monday, February 15 to Friday, February 19, 2010. The hours of data collection are shown in Figure 13.

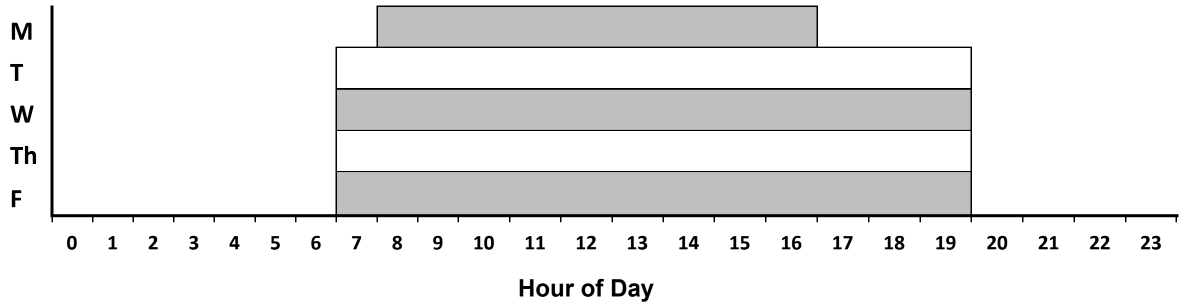


Figure 13: Data Collection Hours at the Emerson Weigh Scale

Note: During the survey, the Emerson weigh scale was open from 07:00 to 20:00, Monday to Friday. Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

The West Hawk weigh scale is located adjacent to the Manitoba-Ontario border and primarily processes interprovincial traffic. The AADTT at this location in 2008 (2009 estimates are not available) was 1,050 in 2008 (Jablonski, et al., 2010). Trucks passing through this scale must comply with both the Manitoba and Ontario truck size and weight regulations. Due to this, Turnpikes are not observed at this location as northwest Ontario does not permit them and this section of PTH 1 is not twinned. The scale is typically operated from 08:00 to 22:00. Data were collected from Monday, February 15, 2010 to Friday, February 19, 2010. The hours of data collection are shown in Figure 14.

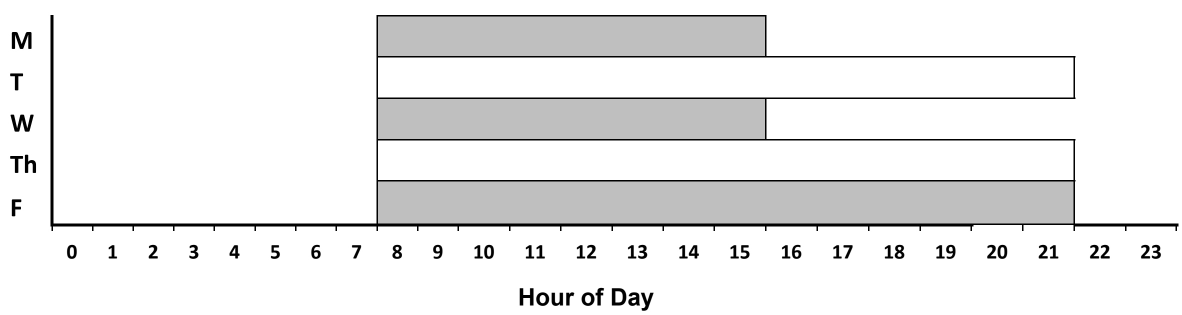


Figure 14: Data Collection Hours at the West Hawk Weigh Scale

Note: During the survey, the West Hawk weigh scale was open from 08:00 to 22:00, Monday to Friday.
Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

Data were collected on axle configuration, number of axles, body type, type of long combination vehicle (LCV) (if applicable), and weights of axle groups. Table 11 shows a sample of the data fields. Axle weights are collected as axle groupings in the order they are measured on the scale. There are eight major body types for 3-S2s collected in this survey. They are the: container, dump, flat deck, hopper, livestock, tanker, dry van, and refrigerated van (reefer).

Table 11: Sample of Weigh Scale Data Collection

Configuration	# of Axles	Body Type	LCV	Axle Weight (kg)					
				Steering	2nd Group	3rd Group	4th Group	5th Group	6th Group
3-S3	6	Flat Deck	-	5450	16320	23360			
3-S3	6	Flat Deck	-	5650	20320	25860			
3-S2-S3	8	Hopper	-	4770	16970	12100	13800		
3-S2	5	Reefer	-	4300	4340	3140			
3-S2-4	9	Van	TPD	5090	8600	6910	6400	4190	

Note: A "-" means not an long combination vehicle (LCV).

Axle weights for each truck configuration are screened to ensure only "realistic entries" are used for calculations. The lower limit of this reality check is defined to be 1,500 kilograms and the upper limit is defined as 150 percent of each axle configuration allowable load limit. For example, the tandem axle weight limit is 17,000 kilograms, therefore all weights recorded between 1,500 kilograms and 25,500 kilograms are accepted for further analysis. Since the GVW is calculated as the sum of the individual axle group weights, if one or more axle weights do not meet the criteria, then the GVW is not further analyzed. The GVW does not have a lower or upper boundary, if all axle weight groupings are valid entries the GVW is used for analysis. This methodology to screen data is consistent with the criteria developed by Tan (2002).

It is important to note that all data were collected during the winter months of January and February. Tan (2002, p 91) states that, "weights in the winter months are generally higher, indicating some effects of the winter weight premiums." Although this is not a limitation in the data, it is important to understand this affect.

For the purposes of this research, valid truck classification depends on each truck being correctly classified by both axle configuration and body type. As the truck drives over the scale, the weight is recorded for each axle grouping. The digital weight reading is recorded once the entire axle group is on the scale. Timing and attention are very important while the surveyor is recording several pieces of information. Some axle spreads are very large that they nearly exceed the length of the scale, these weight readings only appear momentarily.

The combined weight of Turnpike drive and lead trailer tandem axles are approximately seven tonnes heavier than the combined weight of the rear trailer tandem axles (shown in Figure 15). This is in accordance with Turnpike Double permitting regulations, which state that the lead trailer must be heavier than the rear trailer. Axle weights on the lead and rear trailer are analyzed separately to distinguish the trailer loadings.

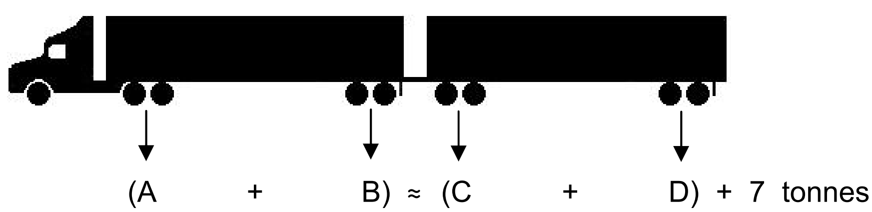


Figure 15: Turnpike Double Axle Weight Distribution

Note: Figure in units of tonnes.

Weigh scale surveys are constrained by the hours of operation of the scales, which are subject to the availability of a Motor Carrier Division officer. If an officer is away for any reason, there may not be a substitute and the weigh scale will not operate. This may result in early closure of the scale or data collection for only one direction of travel. If an officer is performing a vehicle inspection or issuing a citation to a driver, the operation of the scale may be temporarily suspended. These operational characteristics of the scales result in data gaps.

3.4.3 Survey Results

The specialized surveys recorded a total of 8,431 articulated trucks from the Headingley, Emerson and West Hawk weigh scales. Headingley accounted for 50 percent of the counts. This is partially attributed to higher truck volumes and longer hours of operation compared to Emerson and West Hawk which represented 21 and 29 percent of the counts, respectively. The 3-S2s with van trailers and Turnpikes accounted for 46 and four percent of the articulated truck traffic volumes, respectively. Each station recorded a large proportion of van trailers for 3-S2s (dry and refrigerated). Table 12 provides a summary of the 3-S2 and Turnpike counts collected at the weigh scales.

Table 12: Summary of 3-S2 Vans and Turnpikes at Weigh Scales

	Headingley	Emerson	West Hawk	Total
Total Surveyed	4,196	1,783	2,452	8,431
Total 3-S2s	2,308	1,510	1,314	5,132
Total 3-S2s (Vans)	1,922	855	1,099	3,876
Total Turnpikes	322	11	0	333

Note: Data collected for five business days in the months of January and February, 2010.

The proportions of 3-S2s with van trailers and Turnpikes at the Headingley scale are 46 and eight percent, respectively. 3-S3s and 3-S3-S2s are also prominent at this location since the Prairie region has similar

Emerson's proportions of 3-S2s with van trailers and Turnpikes are 48 and less than one percent, respectively. The weigh scale has a lower proportion of Turnpikes than Headingley because of the influence of U.S. truck size and weight regulations that do not permit Turnpikes on the Interstate Highway System. 3-S3 and 3-S3-S2 volumes are very low at the Emerson weigh scale since the U.S. truck size and weight regulations do not allow for their effective use. This results in the high proportion of 3-S2s at this weigh scale.

The West Hawk weigh scale has a 3-S2 (with van trailers proportion of 45 percent. There are no Turnpike observations at this location since these vehicles are not permitted on the undivided highway section adjacent to the Manitoba-Ontario border.

Tandem axle weights on 3-S2s (with van trailers) and Turnpike lead trailers average approximately 11 tonnes for a 17 tonne limit throughout the three stations. This is evidence of cube-out freight in both of these vehicle types. The following presents details from each of the weigh scales.

3.4.3.1 Headingley Weigh Scale

A total of 4,196 trucks were surveyed at the Headingley weigh scale during the week. Figure 16 shows the heavy truck fleet distribution at the scale. The most common vehicle type classified at the scale is the 3-S2 configuration. These trucks account for 55 percent of the recorded truck traffic. The 3-S3 is the second most common and represents 22 percent of the recorded traffic followed by the 3-S3-S2 (eight-axle B-Train) which represents 11 percent. Turnpikes are the fourth most common configuration observed at the Headingley scale. They represent eight percent of the observed trucks. The 3-S2-4 configuration is the most common Turnpike configuration and represents seven percent of total observed trucks, but 92 percent of Turnpike configurations. Four Turnpike different configurations were identified at Headingley. These are shown in Table 13.

Dry and refrigerated vans are the most common representing 38 percent and 29 percent, respectively. This means that 46 percent of observed trucks, at the Headingley scale, are 3-S2s with van body types.

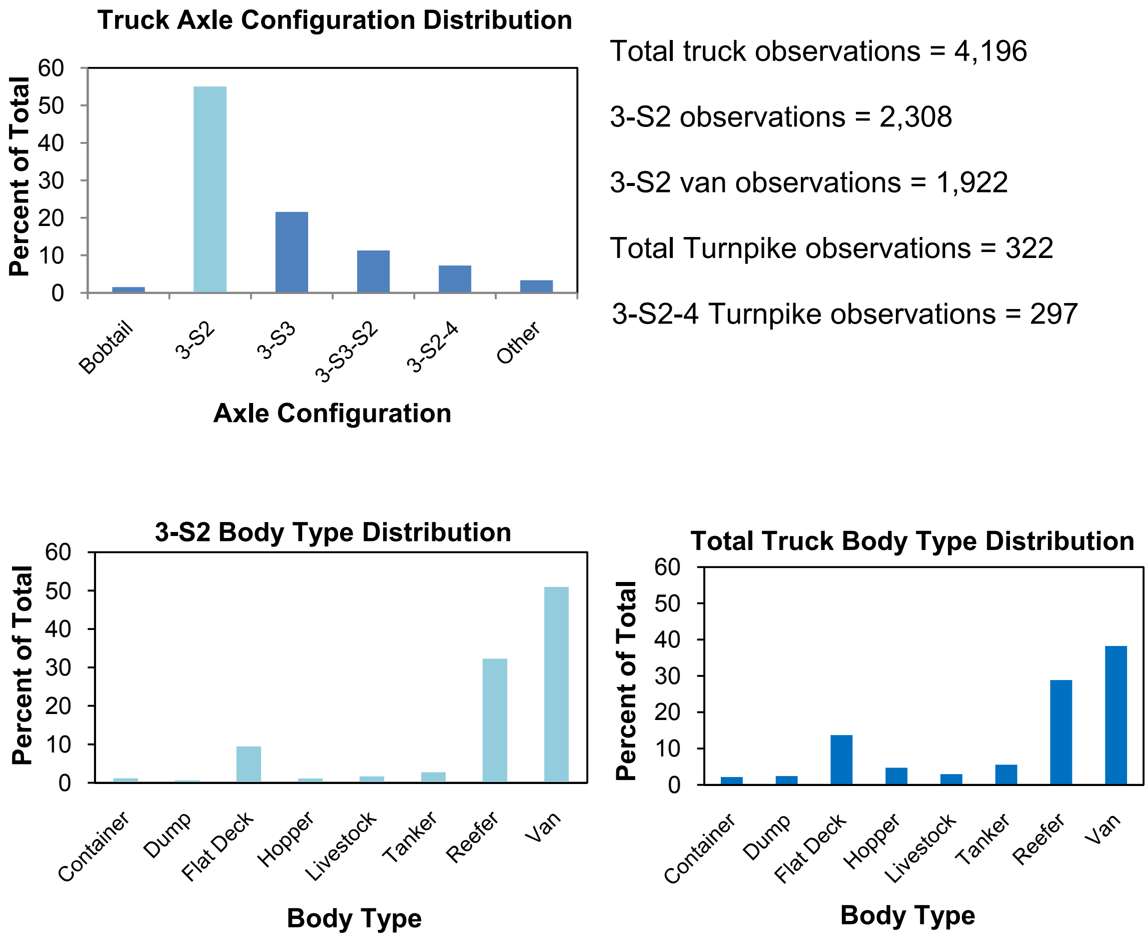


Figure 16: Truck Fleet Distribution at Headingley Scale

Note: Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

Table 13: Headingley Turnpike Double Configurations

Turnpike Double Configuration	Number of Observations
 3-S2-3	11
 3-S2-4	297
 3-S3-4	13
 3-S2-5	1
Sample Size	**322**

Note: Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

The axle weight data was collected in the eastbound and westbound directions at the Headingley scale. Load spectra for the axle groupings can be found in Appendix C. Figure 17 shows the GVW load spectra for 3-S2 vans in the eastbound and westbound directions at Headingley in histograms and cumulative distributions. The mean GVW directional differences of 3-S2 vans between eastbound and westbound travel is 26.5 and 27.0 tonnes, respectively. The eastbound traffic weights peak at approximately 15 and 35 tonnes, suggesting that traffic is more likely to haul weigh-out commodities or be empty. The westbound traffic peaks around 25 tonnes and has less defined peaks around 15 and 35 tonnes. This suggests cube-out or LTL freight around the 25 tonne peak and weigh-out and empty traffic around the 35 tonne and 15 tonne peaks. Five percent of rear trailers were found to be heavier than the lead trailer. These cases do not meet the permit regulation that states the lead trailer must be heavier than the rear trailer. It is possible that some of these cases may occur from human error in recording the axle weight measurements.

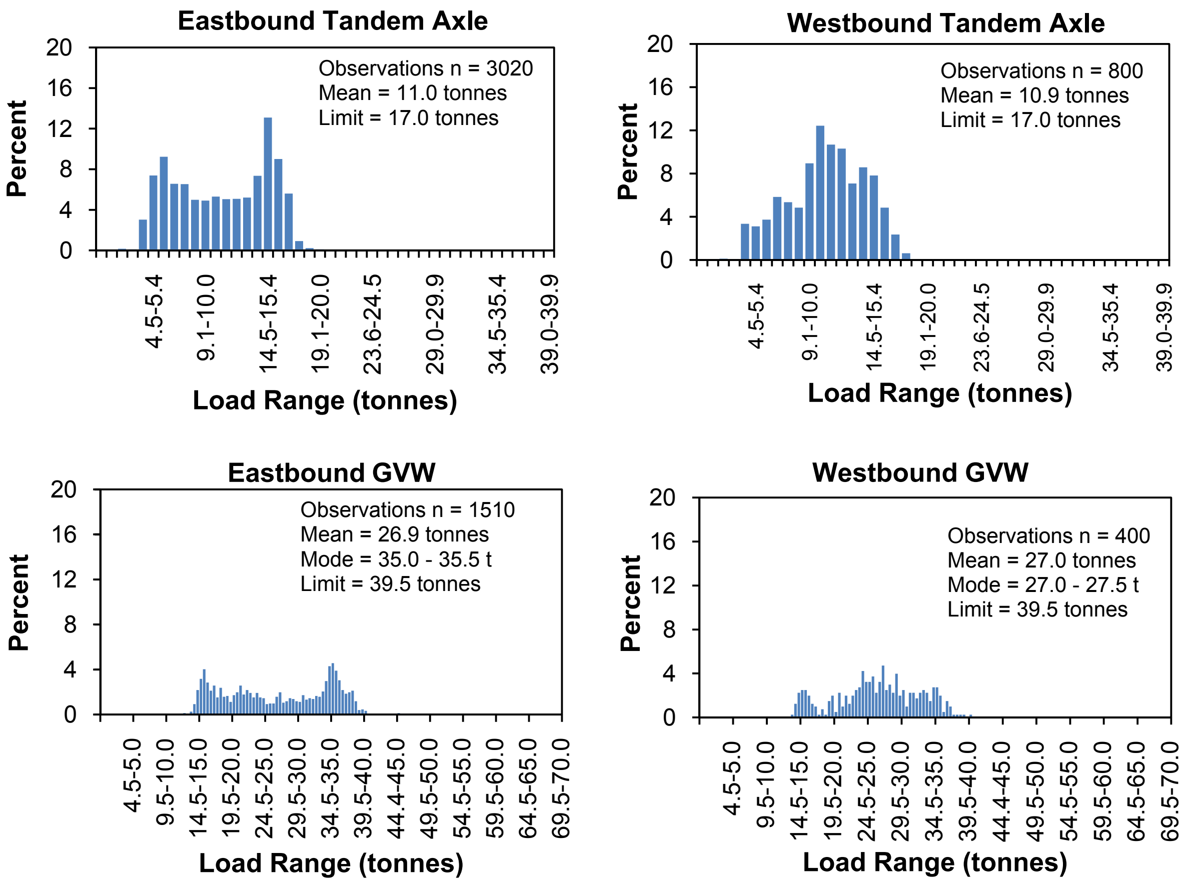
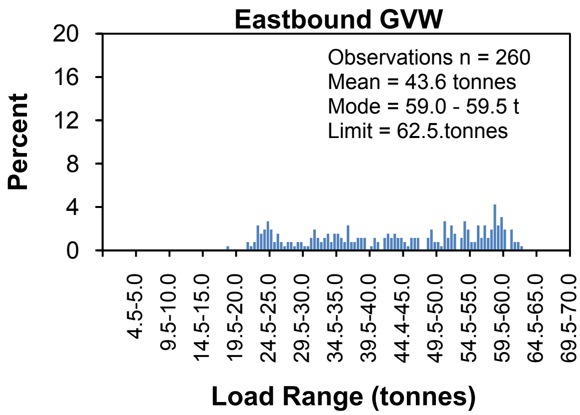


Figure 17: Headingley 3-S2 Van Tandem Axle and Gross Vehicle Weights

Note: Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

The weight data for Turnpikes at Headingley are grouped for the four configurations (shown in Table 13). Figure 18 shows the GVW load spectra for Turnpikes in the eastbound and westbound directions at Headingley in histograms and cumulative distributions similar mean average GVW of 43.6 and 46.1 tonnes in the eastbound and westbound directions. The eastbound direction is fairly even amongst the distribution of weights with moderate peaking around 25 and 59 tonnes, indicating empty and weigh-out freight, respectively. The westbound GVWs peak around 25 and 48 tonnes, indicating empty and cube-out (or LTL) freight, respectively.



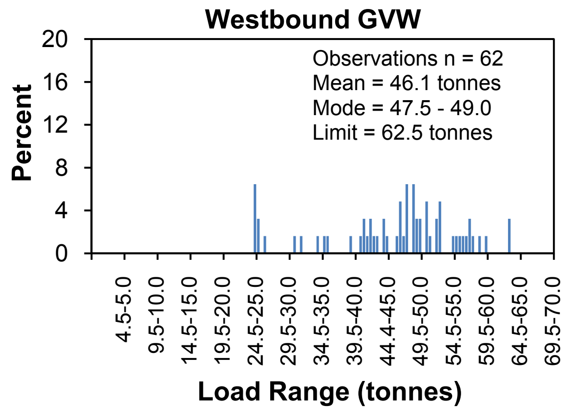


Figure 18: Headingley Turnpike Gross Vehicle Weights

Note: Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

To further understand how the Turnpikes are operating, tandem axle loads are plotted in Figure 19 by: (1) drive and lead trailer tandem axle groups and (2) rear trailer tandem axle groups. The drive and lead trailer tandem axle groups have higher weight limits as required by regulation. These approximately differ by seven tonnes (see Figure 15). Eastbound drive and lead trailer tandem axle groups exhibit peaks around 15 tonnes while the rear trailer tandems peaks around 5 and 13 tonnes. This indicates more weigh-out freight in the lead trailers and more cubic or empty freight in the rear trailers. Westbound traffic exhibits a peaking on the lead trailer tandems between 13 and 16 tonnes and 5 tonnes on the rear trailer. This indicates a higher proportion of loaded freight in the westbound than eastbound direction in both lead and rear trailers.

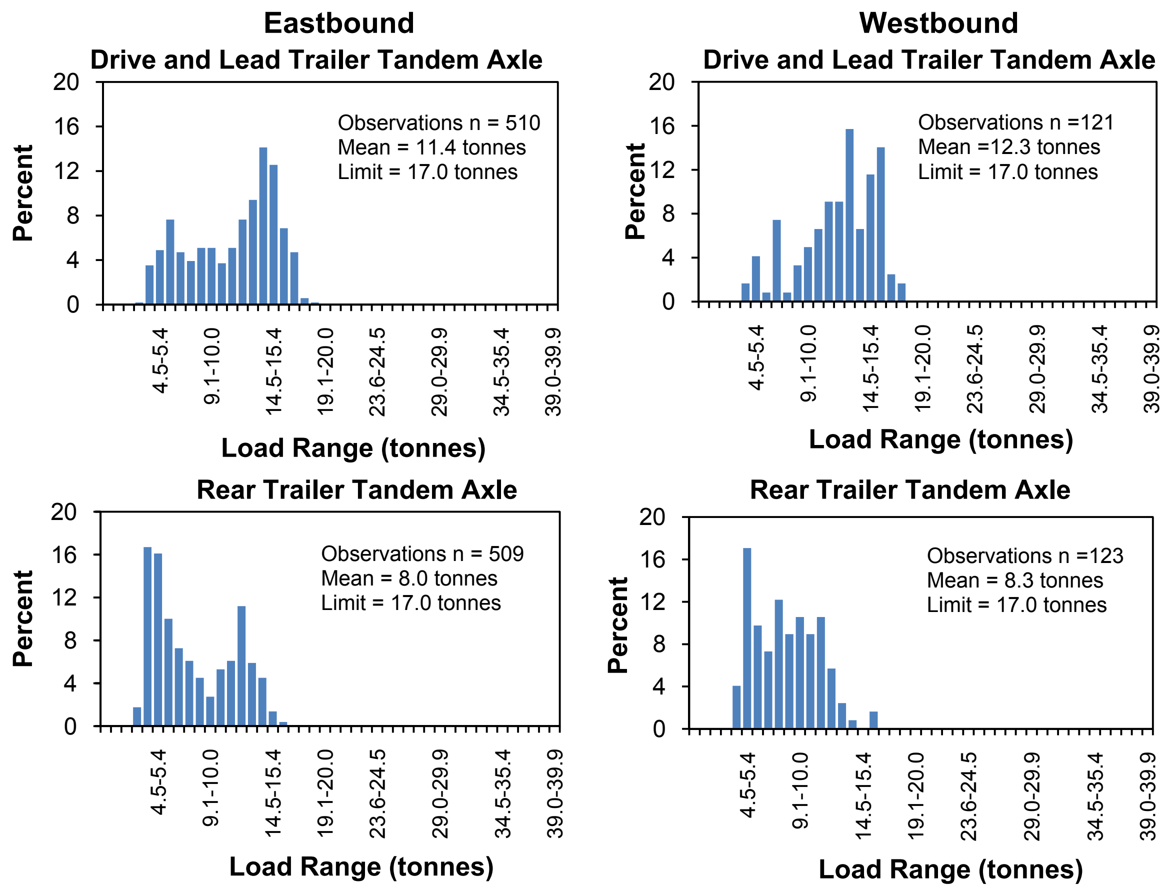


Figure 19: Headingley Turnpike Tandem Axle Weights

Notes: The number of observations varies between trailers since some trailers have single or tridem axles and only tandem axles are shown in this figure.
Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

3.4.3.2 Emerson Weigh Scale

The Emerson scale analysis only shows data for the northbound and southbound directions combined. The survey sampled a total of 1,783 trucks at the weigh scale. Figure 20 shows the heavy truck fleet distribution at Emerson. The most common vehicle type classified at the scale is the 3-S2 configuration, accounting for approximately 85 percent of the recorded truck traffic. The 3-S3 is the next most common configuration and represents eight percent of the truck traffic, followed by the 3-

S3-2, which represents three percent. Turnpikes represent less than one percent of the observed trucks.

Emerson's high proportion of 3-S2s results in similar body type distributions between the total trucks and 3-S2s. Dry and refrigerated vans account for 38 and 13 percent of total trucks, respectively. This means that 48 percent of observed trucks, at the Emerson scale, are 3-S2s with van body types. Dry and refrigerated vans are the most common representing 3 percent and 32 percent respectively.

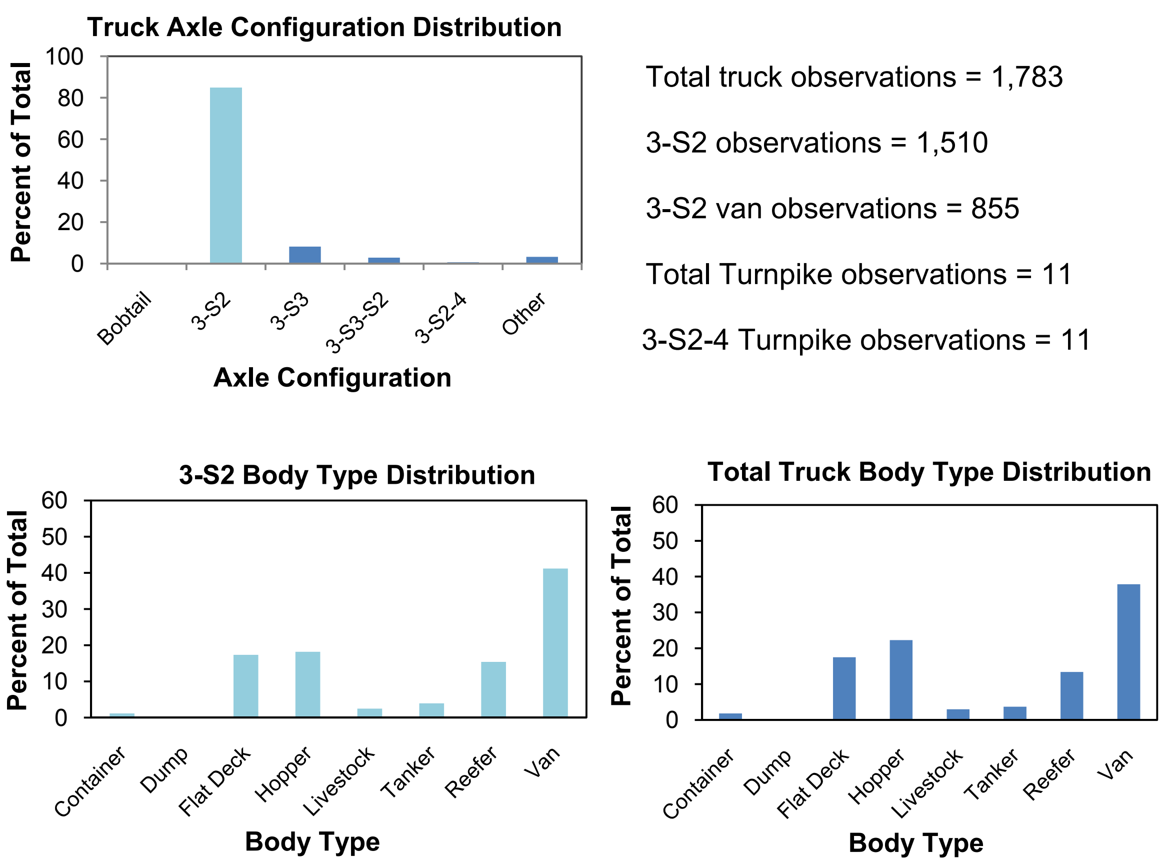


Figure 20: Truck Fleet Distribution at Emerson Scale

Note: Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

The axle weight data was recorded by the northbound and southbound directions combined at the Emerson scale. Load spectra for the axle groupings can be found in Appendix C. Figure 21 shows the GVW load spectra for 3-S2 vans Emerson by histogram and cumulative distribution. The mean GVW of the 3-S2s with van trailers at the Emerson Scale is 26.8 tonnes. This sample size exhibits a negatively skewed distribution peaking at approximately 35 tonnes and suggests that the truck traffic comprises weigh-out commodities and cube-out commodities.

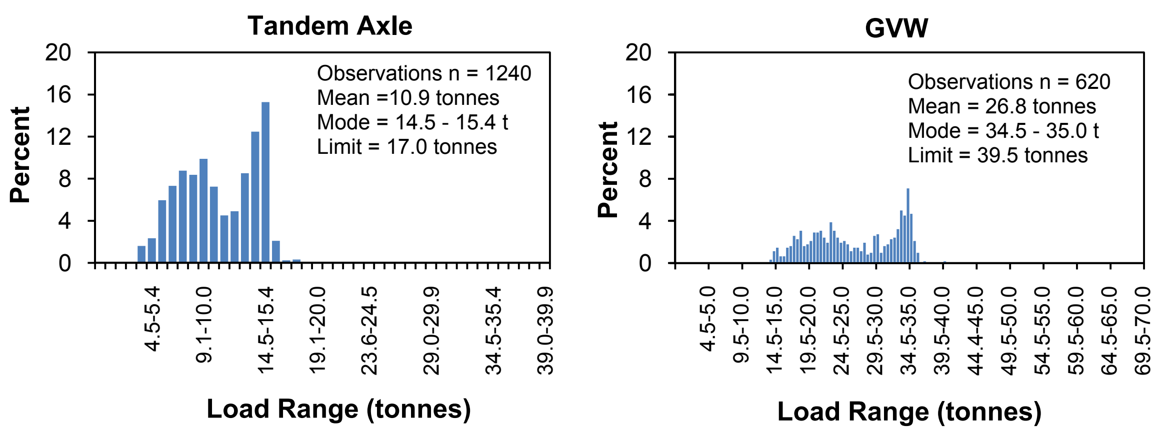


Figure 21: Emerson 3-S2 Van Tandem Axle and Gross Vehicle Weights

Note: Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

3.4.3.3 West Hawk Weigh Scale

A total of 2,452 trucks were surveyed at the West Hawk weigh scale during the week. Figure 22 shows the heavy truck fleet distribution at the scale. The most common vehicle type classified at the scale is the 3-S2 configuration. These trucks account for 54 percent of the recorded truck traffic. The 3-S3 is the second most common and represents 26 percent of the recorded traffic followed by the 3-S3-S2 which represents 15 percent.

Dry and refrigerated vans are the most common representing 45 percent and 38 percent, respectively. This means that 45 percent of observed trucks, at the Headingley scale, are 3-S2s with van body types.

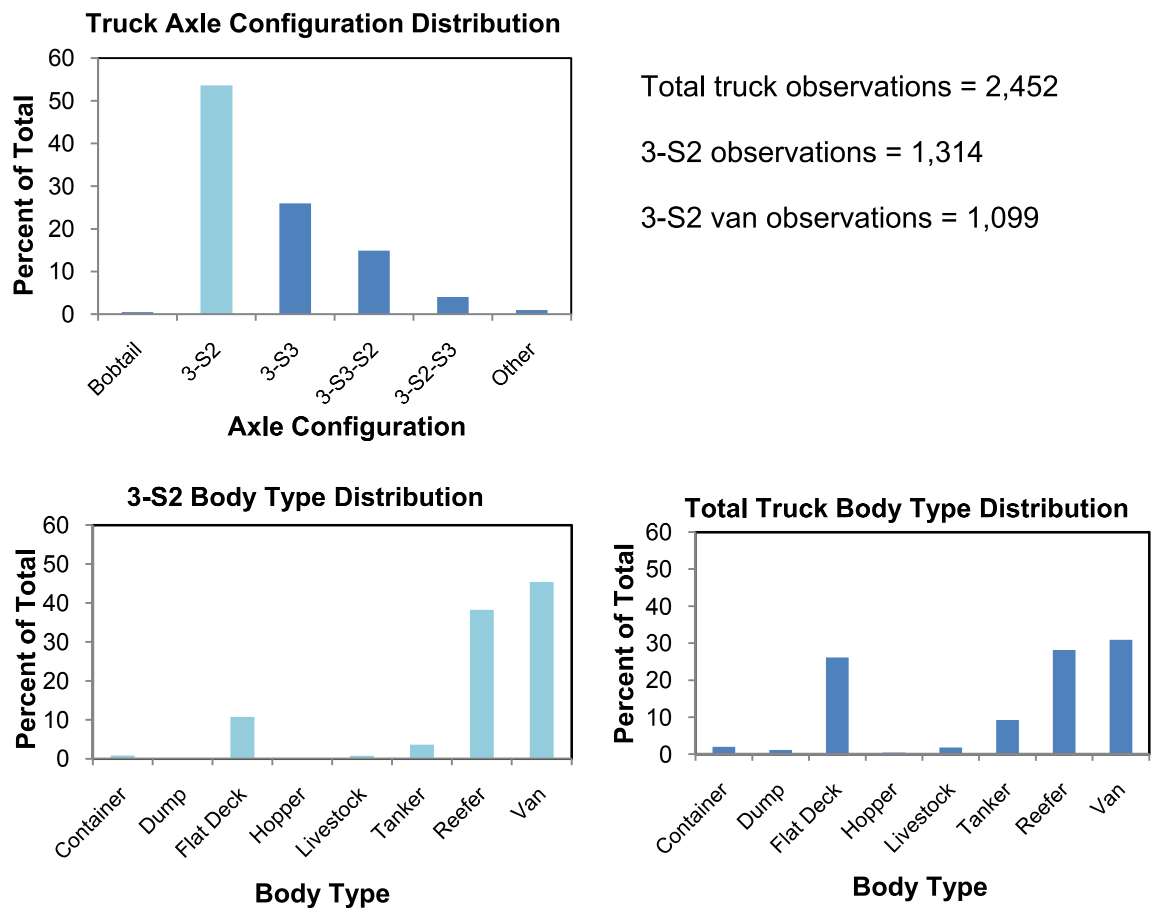


Figure 22: Truck Fleet Distribution at West Hawk Scale

Note: Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

Axle weight data was collected in the eastbound and westbound directions at the West Hawk scale. Figure 23 shows the GVW load spectra for 3-S2 vans in the eastbound and westbound directions at West Hawk in histograms and cumulative distributions. The mean GVW directional differences of 3-S2 vans between eastbound and westbound travel is 26.6 and 27.8 tonnes, respectively. These GVW splits are comparable to the

Headingley weigh scale. The eastbound traffic weights peak at primarily around 15 tonnes, suggesting a significant proportion of empty trucks. Less distinct peaks follow around 25 and 35 tonnes suggesting cube-out and weigh-out freight, respectively. The westbound traffic peaks are not very distinct. They occur around 20, 25, and 35 tonnes. This suggests cube-out or LTL freight around the 20 and 25 tonne peaks and weigh-out around the 35 tonne peak.

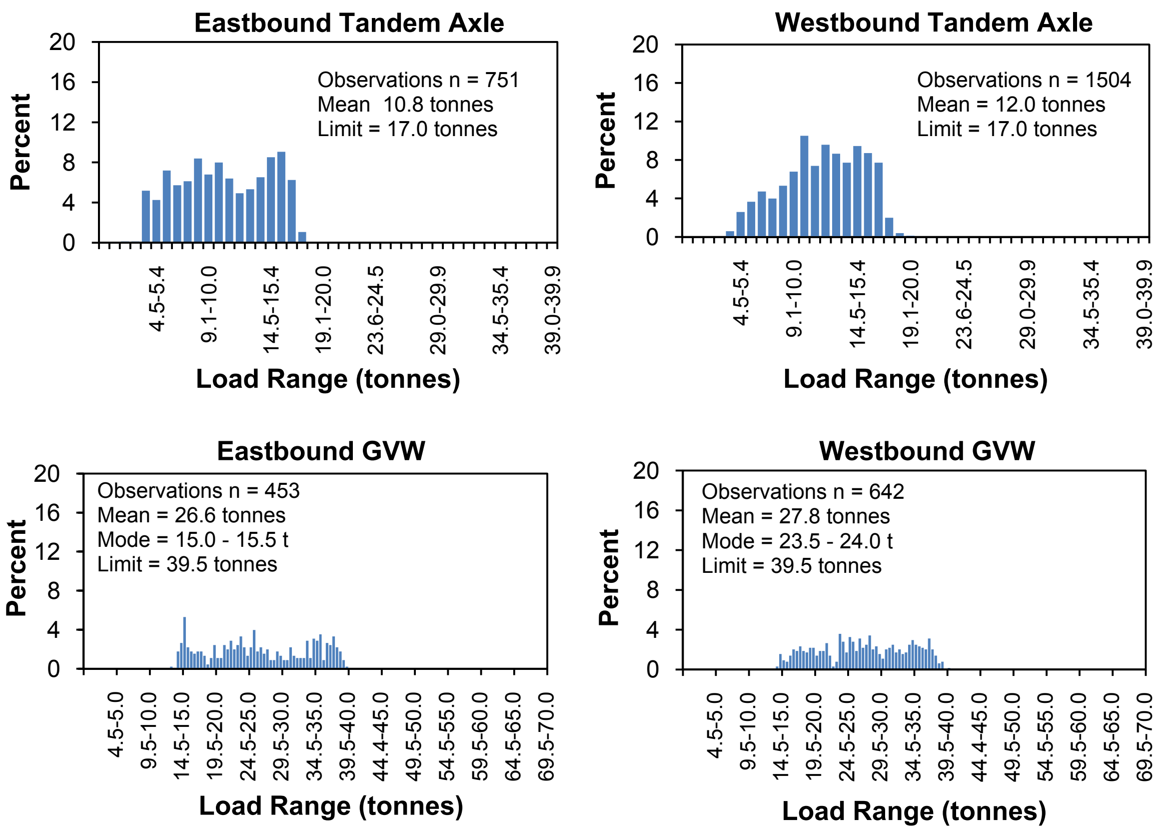


Figure 23: West Hawk 3-S2 Van Tandem Axle and Gross Vehicle Weights

Note: Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

3.5 SUMMARY

The following summarizes key points from the chapter:

- As of January 1, 2011, the Turnpike Double network in the Canadian Prairie region measures 4,100 centreline-kilometres.
- Regulatory prohibitions of Turnpike operations in British Colombia, Ontario, and the United States render certain sections of the Canadian Prairie region's Turnpike Double network to be operationally impractical.
- Heavy truck emission regulations are regulated at the Federal government level in Canada and have been harmonized with the U.S. EPA since 1988. These have targeted: (1) engine manufacturers for NO_x, PM, HC, and CO emissions; (2) fuel suppliers for sulphur content to restrict SO_x emissions; (3) and are now targeting vehicle manufacturers for GHG emissions of CO_2, CH_4, N_2O, and HFCs.
- WIM data on Highway 1 between Winnipeg at MacGregor, MB show a growth of 78 percent in Turnpike volumes from 2005 to 2009. This is partially attributed to: (1) the completion of the divided highway between Virden, MB and Moosomin, SK, which completed the link for Canadian Prairie regional Turnpike Double network; and (2) an economic recession during 2008 and 2009 that caused trucking companies to increase their operation of Turnpikes in order to remain competitive.
- Weigh scale surveys were conducted at three locations in Manitoba for a week in January and February, 2010 to identify axle weight characteristics of Turnpikes and 3-S2s with van trailers (dry and refrigerated). The surveys counted a total of 8,431

articulated trucks and were conducted at the Headingley weigh scale west of Winnipeg, the Emerson weigh scale at the Canada-U.S. border, and the West Hawk weigh scale near the Manitoba-Ontario border.

- The combined weight of Turnpike drive and lead trailer axles are approximately seven tonnes heavier than the combined weight of the rear trailer’s axles. This is in accordance with the Turnpike permitting regulations, which state that the lead trailer must be heavier than the rear trailer. Five percent of the Turnpikes were found to have heavier rear trailers than lead trailers.

- 3-S2s with van trailers represent approximately 45, 46, and 48 percent of the articulated truck fleet samples at the Headingley, Emerson, and West Hawk weigh scales, respectively.

- Tandem axle weights on 3-S2s (with van trailers) and Turnpike lead trailers average approximately 11 tonnes for a 17 tonne limit throughout the three stations. This is evidence of cube-out freight in both of these vehicle types.

4. DEVELOPMENT OF FUEL CONSUMPTION MODELS

This chapter develops the fuel consumption models for Turnpikes and 3-S2s based on: (1) the design and conduct of a survey of carriers that operate Turnpikes in the Canadian Prairie region; (2) integration and normalization of fuel consumption data obtained from carriers; and (3) identification of relationships between key variables affecting fuel consumption.

4.1 ANALYSIS DATA

Information about fuel consumption characteristics was requested from Canadian Prairie-based trucking companies that operate both Turnpikes and 3-S2s in the region. The survey consisted of a request for fuel consumption performance data (by vehicle type) and a questionnaire about the company's strategies to reduce fuel consumption through technological investments and program development. The questionnaire is addressed in Section 3.3.1.

Table 14 provides the fuel consumption data elements (fields) requested by the survey. The survey focuses on trip-based data for Turnpikes and 3-S2 vans to enable evaluation of the fuel consumption performance of the two vehicle configurations.

Table 14: Fuel Consumption Data Survey Fields

Field	Units	Description
VIN	-	Vehicle identification number
START_DATE	-	Start date of trip
START_TIME	-	Start time of trip
END_DATE	-	End date of trip
END_TIME	-	End time of trip
ORIGIN_CITY	-	Start location of trip
DESTINATION_CITY	-	End location of trip
DISTANCE	kilometres	Total trip distance
AVERAGE_SPEED	kilometres per hour	Average trip speed in transit
FUEL_CONSUMED	litres	Fuel used during trip
CONFIGURATION	3-S2 or Turnpike	Vehicle configuration for van trailers
COMMODITY	-	Cargo commodity
GVW	tonnes	Operating gross vehicle weight
TARE	tonnes	Vehicle tare weight
CUBIC_CAPACITY	cubic metres	Cube capacity of vehicle trailers
CUBIC_LOAD	% of capacity	Percent cubic fill
IDLING_TIME	hours	Time spent idling during trip

The surveyed carriers could not provide data on cubic load, idling, or GVW measurements. However, fuel consumption data and VKT by tractor and vehicle type were provided on a monthly basis from 2006 to 2009, but data are not available for all months.

The datasets provided by the carriers have the following common data elements:

- Year
- Month
- Tractor ID
- Tractor year (relevant to emissions production)
- Fuel purchases (in litres) by month by tractor
- Kilometres travelled by month by tractor
- Vehicle type (3-S2 or Turnpike)

Fuel consumption (in litres per 100 kilometres of travel) was calculated from the monthly fuel purchases and kilometres travelled by vehicle. As the vehicle's kilometres of travel increase in a given month, the litres of fuel purchased approach the litres of fuel consumed. Shorter trips result in more fuel purchased than consumed for the distance travelled, thus skewing the fuel consumption value upward.

To normalize the data and remove outliers, an analysis was performed to test the sensitivity of the average fuel consumption and standard deviation to VKT level. The purpose of this analysis is to determine a VKT level above which the average fuel consumption is constant with respect to VKT and the standard deviation is acceptable. By removing data records with VKT below this level, the data skew is removed and the distribution becomes normal. Figure 24 and Figure 25 show the distributions of average fuel consumption, the effect of outliers on the measurement, and the standard deviation for a 3-S2 and Turnpike, respectively. In both figures, as the level below which monthly VKT trip data records are removed increases: (1) the standard deviation decreases; and (2) the average fuel consumption approaches a constant value. Table 15 provides details of the analysis on the sensitivity of the normalization process. From the analysis, a VKT of 1,600 kilometres (1,000 miles) was chosen as the level below which data records were removed for standardization purposes. Since VKT data was provided in units of miles and standard deviations for each sample level stabilize around 1,500 km, 1,000 miles (1,600 km) was used as the cut-off point.

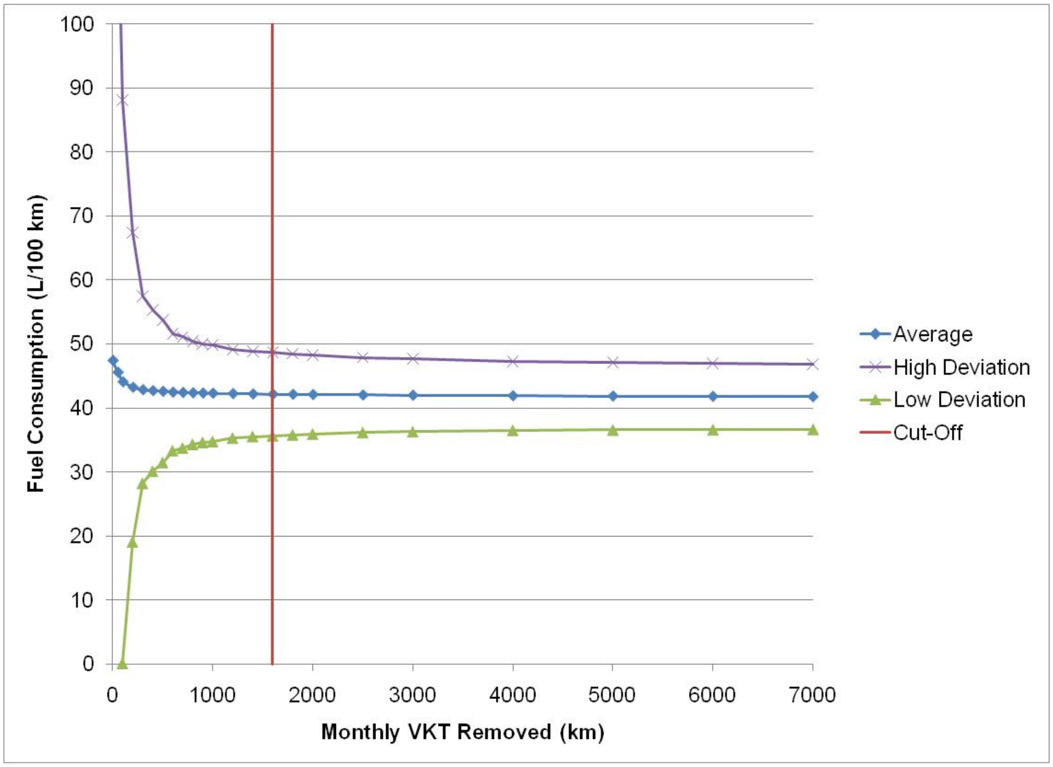


Figure 24: Distribution of 3-S2 Fuel Consumption by VKT for 2006 to 2009

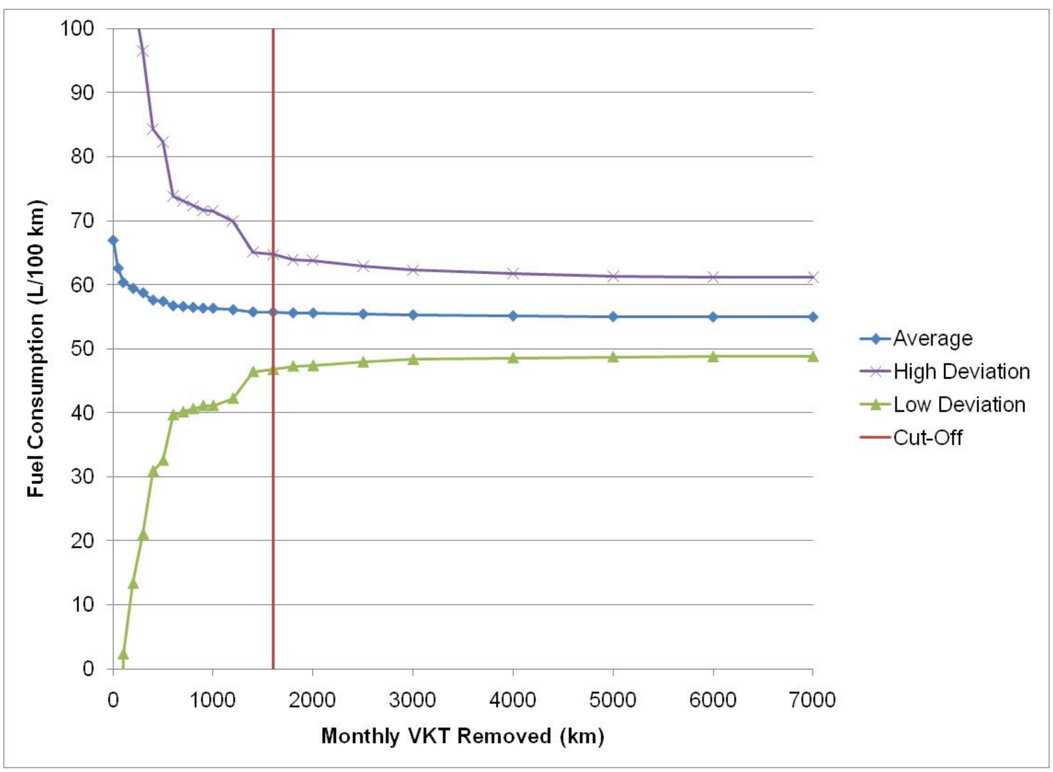


Figure 25: Distribution of Turnpike Fuel Consumption by VKT for 2006 to 2009

Table 15: Vehicle Fuel Consumption Statistics and Screened VKT

Screened VKT (≤ x km)	Fuel Consumption							
	3-S2				Turnpike Double			
	Average (L/100km)	Standard Deviation (L/100km)	% Cut	Remaining Records (n)	Average (L/100km)	Standard Deviation (L/100km)	% Cut	Remaining Records (n)
0	47.5	120.4	0.00	18758	67.0	200.5	0.00	5090
50	45.6	74.4	0.05	18749	62.6	106.4	0.08	5086
100	44.1	44.0	0.13	18734	60.4	58.1	0.18	5081
200	43.2	24.2	0.20	18720	59.5	46.1	0.26	5077
300	42.9	14.6	0.29	18704	58.8	37.7	0.33	5073
400	42.7	12.6	0.35	18693	57.6	26.7	0.55	5062
500	42.6	11.1	0.39	18685	57.4	24.9	0.59	5060
600	42.5	9.1	0.46	18672	56.7	17.1	0.83	5048
700	42.4	8.7	0.51	18663	56.6	16.5	0.90	5044
800	42.4	8.1	0.57	18652	56.5	15.8	1.02	5038
900	42.3	7.7	0.60	18645	56.4	15.3	1.18	5030
1000	42.3	7.5	0.67	18633	56.3	15.2	1.22	5028
1200	42.2	6.9	0.82	18605	56.1	13.9	1.47	5015
1400	42.2	6.7	1.01	18568	55.8	9.3	1.83	4997
1600	42.2	6.5	1.14	18544	55.7	9.0	1.87	4995
1800	42.1	6.3	1.24	18525	55.6	8.3	2.08	4984
2000	42.1	6.2	1.38	18500	55.6	8.2	2.34	4971
2500	42.0	5.9	1.80	18420	55.4	7.5	3.01	4937
3000	42.0	5.7	2.11	18362	55.3	7.0	3.67	4903
4000	41.9	5.4	2.81	18230	55.1	6.6	4.97	4837
5000	41.9	5.3	3.49	18104	55.0	6.3	6.52	4758
6000	41.8	5.2	4.25	17960	55.0	6.2	8.17	4674
7000	41.8	5.1	5.11	17800	55.0	6.2	9.71	4596

Notes: Data sample collected from Canadian Prairie based motor carriers from 2006 to 2009.
The table indicates monthly truck trips at or below an indicated VKT level that are removed from the fuel consumption rate estimation.

4.2 IDENTIFICATION OF RELATIONSHIPS

This section identifies relationships evident from the fuel consumption data between fuel consumption and: vehicle type, season, average payload weight, and cubic capacity.

4.2.1 Fuel Consumption by Vehicle Type

The fuel consumption data for 3-S2s and Turnpikes exhibits a normal distribution. Therefore, standard statistical techniques can be used to compare fuel consumption characteristics between the two vehicle types. Table 16 shows a statistical summary of fuel consumption data for each vehicle type; Figure 26 shows the normal distributions for the fuel consumption data graphically. On average, the fuel consumption rate for Turnpikes is 55.7 litres per 100 kilometres of travel. By comparison, 3-S2s consumed fuel at a rate of 42.2 litres per 100 kilometres of travel. The standard deviation is larger for Turnpikes than 3-S2s. This reflects the smaller sample size and the wider operational variability of Turnpikes (in terms of hauling full, partial, and/or empty loads in any of the trailers). The standard error is almost negligible due to the large sample size. Comparing the fuel consumption rate for Turnpikes to the operation of two 3-S2s, Turnpikes potentially save 28.7 litres of fuel per 100 kilometres of travel. This equates to a 34 percent fuel savings. These results are comparable to the findings of L-P Tardif & Associates Inc. (2006), which estimated 28.8 litres per 100 kilometres fuel savings of Turnpikes over two 3-S2s.

Table 16: Statistical Summary of Vehicle Fuel Consumption Data

	Five-Axle Tractor Semitrailer	Turnpike Double
Average Fuel Consumption (L/100 km)	42.2	55.7
Standard Deviation (L/100 km)	6.5	9.0
Standard Error (L/100 km)	0.05	0.07
Sample Size	18,544	4,995
Total Kilometres of Sample (millions)	335	77

Note: Data sample collected from Canadian Prairie based motor carriers from 2006 to 2009.

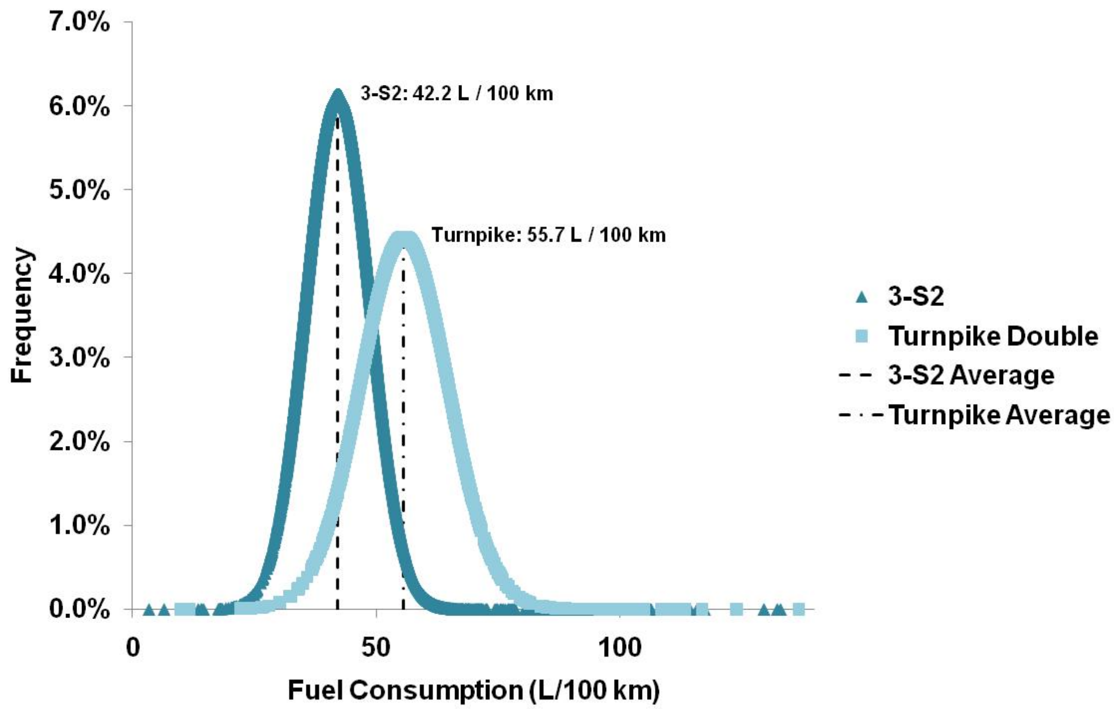


Figure 26: Normal Distributions of Fuel Consumption of a 3-S2 versus a Turnpike

Note: Data sample collected from Canadian Prairie based motor carriers from 2006 to 2009.

A statistical t-test is performed on these two datasets to determine whether they are significantly different to a reasonable level of confidence. Table 17 summarizes the variables of the t-test. The analysis yields a 99.9 percent confidence level that the fuel consumption of Turnpikes is significantly different from that of 3-S2s. Since the fuel consumption is significantly different for the two vehicle types, there is equal confidence that a Turnpike results in less fuel consumption per 100 kilometres of travel when compared to two 3-S2s.

Table 17: t-Test Variables

Parameter	3-S2	Turnpike Double
Average (L/100 km)	42.2	55.7
Sample Size	18,545	4,995
Degrees of Freedom	23538	
Pooled Variance, s_p^2	50.5	
Standard Error	0.11	
t-Value	119.7	
t-Critical for 99.9% Confidence	3.291	

Notes: Pooled t-test assumes the variances are unknown and equal.
Data sample collected from Canadian Prairie based motor carriers from 2006 to 2009.

4.2.2 Fuel Consumption by Season

Fuel consumption is analyzed by season to understand its variation. Seasons are defined as follows for this analysis:

- Winter: December, January, and February
- Spring: March, April, and May
- Summer: June, July, and August
- Fall: September, October, and November

Table 18 shows the average fuel consumption by season for Turnpikes and 3-S2s and their standard deviations. For both vehicle types, fuel consumption is highest in winter and lowest in the summer. Winter is expected to consume the most fuel from idling to heat the cab and to keep the fuel and engine warm (Stodolsky et al., 2000).

Table 18: 3-S2 and Turnpike Fuel Consumption by Season

Season	3-S2		Turnpike	
	Average (L/100 km)	Standard Deviation (L/100 km)	Average (L/100 km)	Standard Deviation (L/100 km)
Winter	45.4	6.5	60.1	7.9
Spring	41.8	5.9	56.1	8.6
Summer	40.6	6.5	52.5	8.5
Fall	41.0	5.9	55.1	9.2
Annual	42.2	6.5	55.7	9.0

Note: Data sample collected from Canadian Prairie based motor carriers from 2006 to 2009.

Figure 27 shows the fuel consumption savings incurred by operating one Turnpike compared to two 3-S2s. Savings in fuel consumption from operating a Turnpike Double in place of two 3-S2s is about 30.7 litres per 100 kilometres in the winter and 28.8 litres per 100 kilometres in the summer.

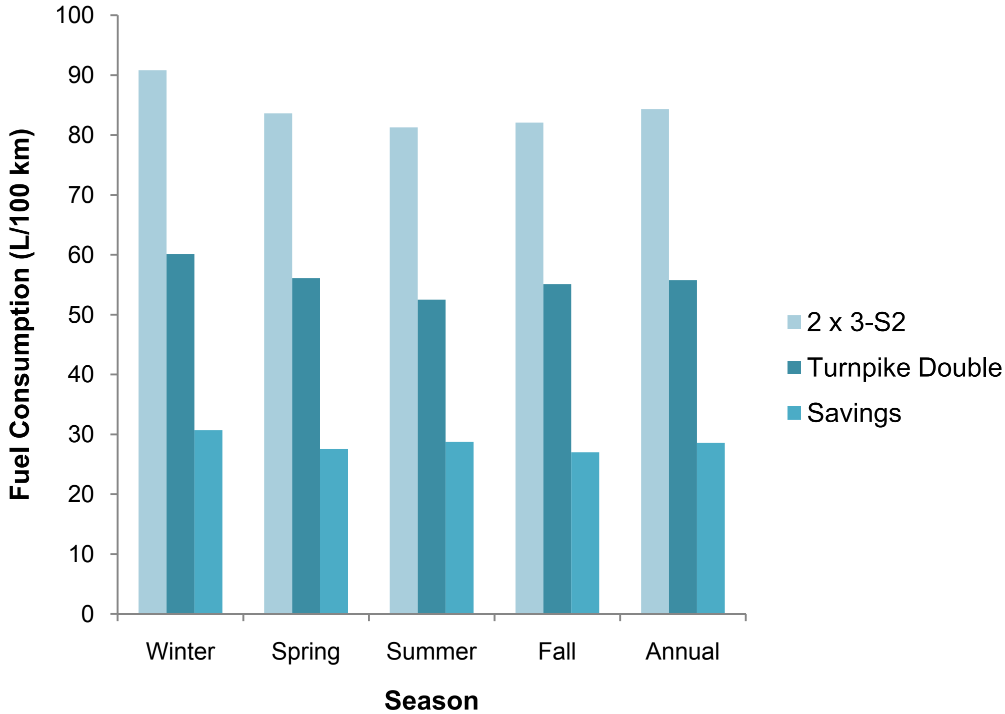


Figure 27: Average Fuel Consumption by Season for Turnpikes and Two 3-S2s

Note: Data sample collected from Canadian Prairie based motor carriers from 2006 to 2009.

4.2.3 Fuel Consumption by Average Payload Weight

Determining fuel consumption on the basis of metrics relevant to the freight transport task allows for a comparative analysis of the fuel efficiency of the freight task. One such metric is fuel consumption per payload tonne-kilometre. To develop this metric, average operating GVWs (for Turnpikes and 3-S2 vans) were collected at three weigh scales located on the Turnpike Double network in Manitoba during the course of this research (see Section 3.4.2 for further details about the data collection). A total of 3,858 3-S2s and 333 Turnpikes were weighed at the two scales. Average GVWs were estimated from this data to be 27,100 kilograms for 3-S2s and 44,100 kilograms for Turnpikes. Once the average GVWs were calculated, vehicle tare weight estimates were subtracted to determine average payload weights. The tare weight estimates are 14,550 kilograms for 3-S2s and 22,730 kilograms for Turnpikes. These estimates are provided from Tunnell (2008). On average, 3-S2s carry 12,550 kilograms of payload and Turnpikes carry 21,370 kilograms of payload. The average fuel consumption per payload weight is given by Equation 1.

$$AFCW_i = \frac{AFC_i}{APL_i} \qquad (1)$$

Where:

$AFCW_i$ = *Average fuel consumption per payload weight for vehicle type i.*

AFC_i = *Average fuel consumption rate for vehicle type i.*

APL_i = *Average payload weight for vehicle i.*

The following is a sample calculation using Equation 1 to determine the average fuel consumption per payload weight for a 3-S2.

$$AFCW_i = \frac{AFC_i}{APL_i}$$

$$AFCW_i = \frac{42.2 \frac{Litres}{100\ kilometres}}{12.55\ tonnes}$$

$$AFCWi = 3.4\ litres\ per\ tonne\text{-}100\ kilometres$$

The average fuel consumption rate is 3.4 litres per tonne-100 kilometres for 3-S2s and 2.6 litres per tonne-100 kilometres for Turnpikes. On a tonne-kilometre basis, Turnpikes use 24 percent less fuel than 3-S2s.

4.2.4 Fuel Consumption by Cubic Capacity

It is useful to consider fuel consumption in terms of cubic capacity since Turnpikes primarily operate under cube-out rather than weigh-out conditions. Since carriers could not provide data on actual cubic load, cubic capacity is used to analyze fuel consumption. A 16.2-metre (53-foot) semitrailer can hold 52 pallets: 13 along the length, two wide, and two high. A Turnpike can carry 104 pallets. The average fuel consumption per pallet is given by Equation 2.

$$AFCP_i = \frac{AFC_i}{ACCP_i} \tag{2}$$

Where:

$AFCP_i$ = *Average fuel consumption per pallet for vehicle type i.*

AFC_i = *Average fuel consumption rate for vehicle type i.*

$ACCP_i$ = *Cubic Capacity (Pallets) for vehicle i.*

The following is a sample calculation using Equation 2 to determine the average fuel consumption per pallet for a 3-S2.

$$AFCP_i = \frac{AFC_i}{ACCP_i}$$

$$AFCW_i = \frac{42.2\,\frac{Litres}{100\ kilometres}}{52\ pallets}$$

$$AFCWi \quad = 0.81\ litres\ per\ pallet\text{-}100\ kilometres$$

The average fuel consumption rate is 0.81 litres per pallet-100 kilometres for 3-S2s and 0.54 litres per pallet-100 kilometres for Turnpikes. On a pallet-kilometre basis, Turnpikes use 33 percent less fuel than 3-S2s.

5. ESTIMATING SYSTEM-WIDE EFFECTS OF TURNPIKE DOUBLES

This chapter provides the system-wide estimates of fuel consumption and emissions effects of Turnpikes in Manitoba. It describes Turnpike and 3-S2 exposure data sources and estimates and combines them with the models developed in Chapter 4 to calculate the system-wide effects of Turnpikes.

5.1 ANALYSIS NETWORK

The analysis network is comprised of the Turnpike Double network within Manitoba for which daily traffic exposure estimates of Turnpikes are at least one vehicle per day. This network, Figure 28, consists of 630 centreline-kilometres and is referred to as the Manitoba Effective Turnpike Double Network (METD-Network). This network is defined for 2009 Turnpike exposure and is comprised of the following routes:

- Highway 1 (Trans Canada Highway), from the Saskatchewan border to the beginning of the undivided section near the Ontario border;
- Highway 75, from the U.S. border to Highway 100 (the south Perimeter Highway);
- Highway 100 (the south Perimeter Highway), from Highway 1 (west junction) to Highway 1 (east junction);
- Highway 101 (the north Perimeter Highway), from Highway 1 (west junction) to Highway 1 (east junction);
- Highway 12, from Highway 1 to Steinbach; and

- Highway 221 and Route 90, from Highway 101 to the City of Winnipeg municipal boundary.

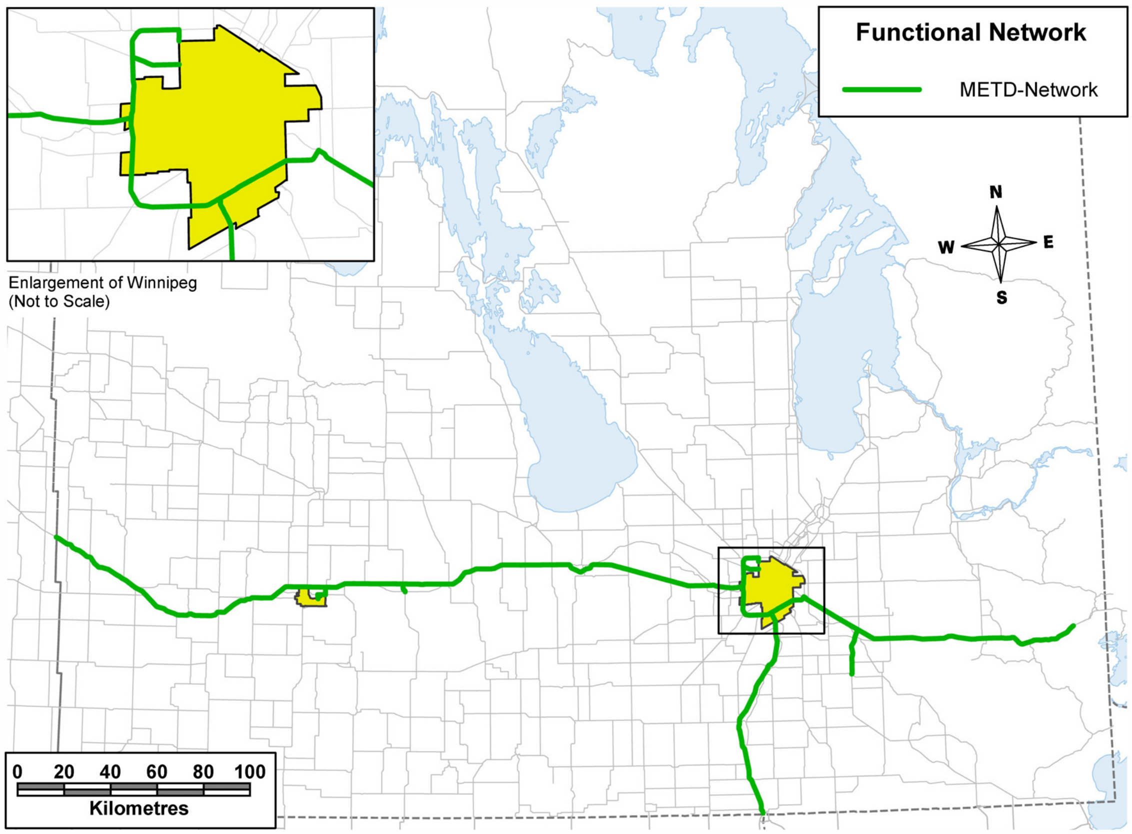


Figure 28: Manitoba Effective Turnpike Double Network

Note: Network measures 630 centreline-kilometres and is defined for the Turnpike Double network for links that have volumes of at least one Turnpike per day.

5.2 EXPOSURE DATA SOURCES

This section describes the sources of data for Turnpike and 3-S2 exposure data.

5.2.1 Turnpike Double Exposure Data Sources

Three sources for Turnpike exposure data are used in this research: weigh-in-motion (WIM) devices, manual classification counts, and industry intelligence. The exposure data estimates are updated for 2009 from the 2006 data in Regehr (2009) as part of this research. A classification algorithm developed by Regehr (2009) is used to isolate and classify Turnpikes from raw WIM data. The locations of the stations are shown in Figure 29; details about the WIM sites are in Section 3.4.1.

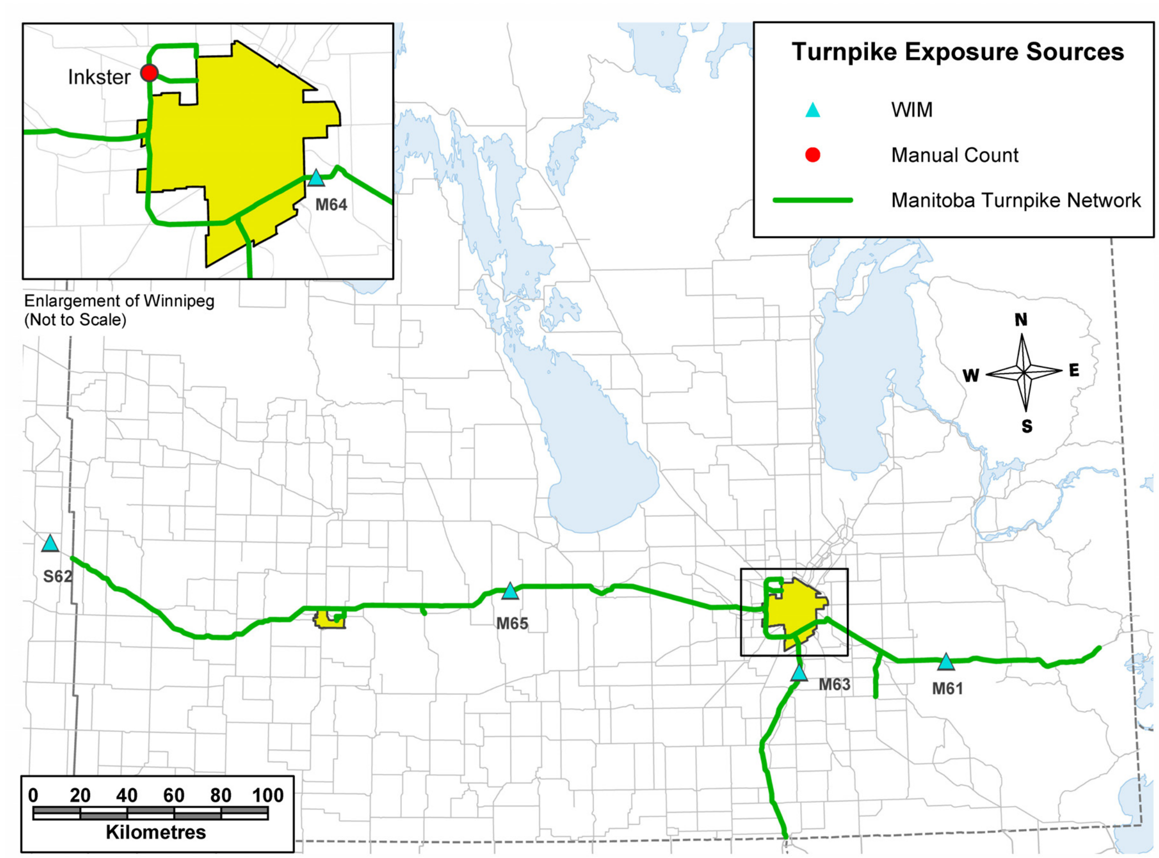


Figure 29: Turnpike Double Exposure Data Sources on the METD-Network

WIM devices provide the primary data source for estimating Turnpike exposure. Raw WIM datasets have the following characteristics:

- Each record in the dataset corresponds to one vehicle passage in one travel lane.

- Records have at least the following attributes: station number, lane or flow direction, date, time, speed, vehicle length, GVW, axle weights, and the separation between subsequent axles.
- Depending on the particular equipment configuration, some WIM records have the following additional attributes: number of axles, vehicle classification (based on either a predefined or user-defined classification scheme), and equivalent single axle load (ESAL).

WIM data are obtained from five stations on the METD-Network. Station S62, a Saskatchewan site adjacent to the Saskatchewan-Manitoba border, is used to estimate Turnpike exposure east of the station.

Manual truck classification counts conducted at the intersection of Highways 101 and 221 on the METD-Network in 2009 also provide data about Turnpike exposure. The counts provide short-term samples of Turnpikes and other types of articulated trucks including 3-S2s and their body types. These counts were collected by the University of Manitoba Transport Information Group. Temporal details about these counts are provided in Appendix D.

The development of system-wide exposure estimates requires the integration of industry intelligence into the exposure knowledge base. Local industry knowledge about Turnpike operations supplements data obtained from WIMs and manual classification counts and enables interpretation of patterns, trends, and anomalies observed in these data (Fortowsky and Humphries 2006).

Industry intelligence was gathered from:

- government officials from Manitoba involved with the measurement and estimation of truck traffic exposure, the administration of freight and truck policy, the development and implementation of trucking programs, and the on-road enforcement of truck size, weight, and safety regulations;
- representatives from trucking companies that operate Turnpikes in the region;
- truck drivers with experience operating Turnpikes;
- researchers with expertise in freight transport systems and trucking; and
- field-based observations of actual Turnpike operations (and trucking in general).

5.2.2 Five-Axle Tractor Semitrailer Exposure Data Sources

Three sources for 3-S2 exposure data are used in this research: permanent classification counts, sample classification counts, and specialized body type surveys. Data obtained from permanent classification counts and sample classification counts are routinely collected via the Manitoba Highway Traffic Information System (MHTIS); details about how these data are collected are provided in Jablonski et al. (2010). This thesis updates these 2008 estimates to 2009 with updated permanent classification counts and AADT estimates throughout the network. The WIM data used for 3-S2 exposure are sourced from sites that have both WIM and AVC counters and are referred to as WIM/AVC sites.

Two types of permanent classification counts are used to develop exposure estimates for 3-S2s: WIMs and AVCs. Each device provides data about vehicle speed, length, and the separation between subsequent axle groups (which is used to classify vehicles using the FHWA 13-category vehicle classification scheme). WIMs provide additional data on

GVW and axle weights. Five-axle tractor semitrailers are considered Class 9 vehicles in this scheme. Body type information is not available from WIMs or AVCs.

There are five AVC stations and four WIM/AVC stations on the METD-Network. These sites are shown in Figure 30; details are provided in Appendix D.

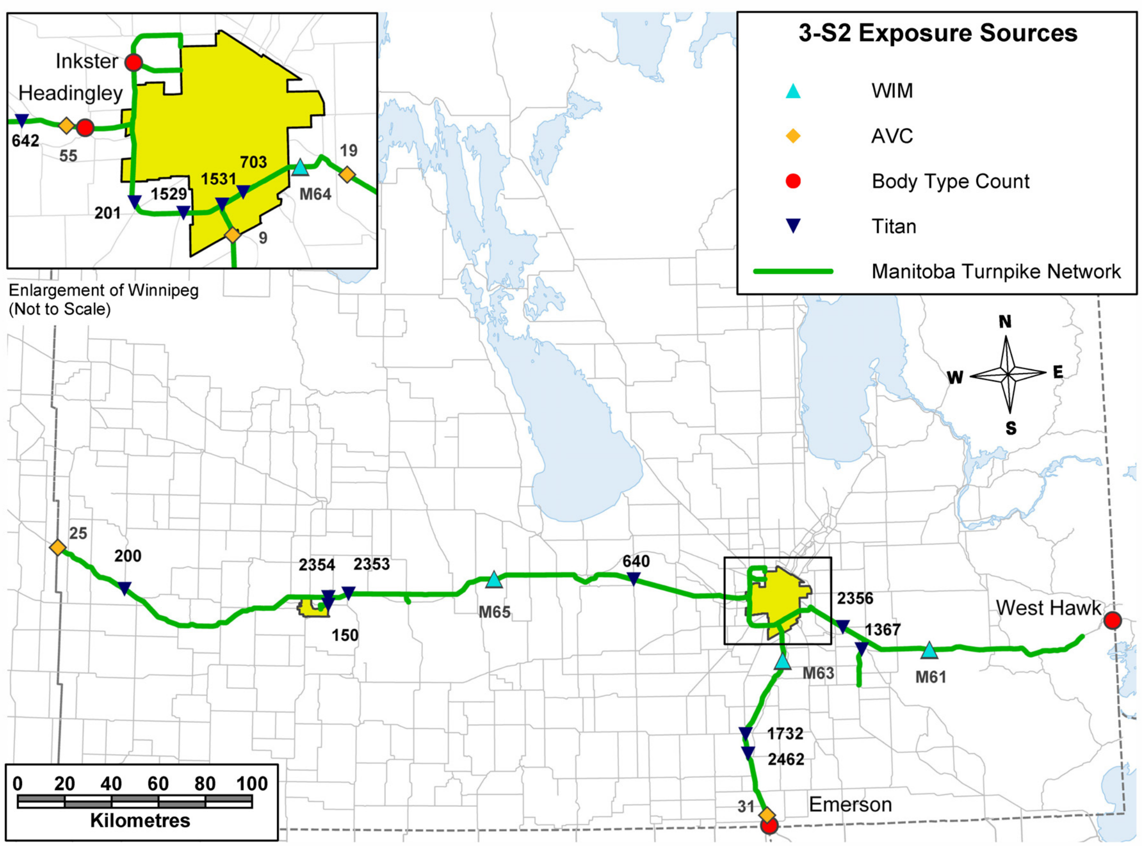


Figure 30: 3-S2 Exposure Data Sources on the METD-Network

Manual turning movement classification (Titan) counts supplement the permanent classification data obtained from the WIMs and AVCs. Titan counts are conducted by Manitoba Infrastructure and Transportation (MIT) on an as-required basis. Titan counts used for this research provide data for 14-hours (typically from 07:00 to 21:00) and classify vehicles using the FHWA 13-category vehicle classification scheme. Each leg of the intersection at which a Titan count is conducted is considered its own count. A total of 14 Titan count locations (13 counts by leg) on the METD-Network are used in this research. The locations of these sites are shown in Figure 30; details are provided in Appendix D.

Since Turnpikes are being compared to 3-S2 vans, it is necessary to estimate the proportion of 3-S2s that operate with a van (or refrigerated van) body type. This information is not available from the permanent or sample classification counts. To obtain this data, specialized body type surveys were conducted at four locations on the METD-Network for this research. Three of these surveys were conducted at weigh scales (See Section 3.4.2): (1) Headingley; (2) Emerson; and (3) West Hawk. The other count was located at the intersection of the north Perimeter Highway (Highway 101) and Inkster Boulevard (Highway 221). The summary of the 3-S2s with van body types are shown in Table 19.

Table 19: Summary of Body Type Survey 3-S2 Proportions

Location	Articulated Trucks Observations	Proportion of 3-S2s (%)	Proportion of 3-S2s with Van Body Types [a] (%)
Headingley	4,196	55.0	45.8
Emerson	1,783	84.7	48.0
West Hawk	2,452	53.6	44.8
Inkster	4,668	58.9	35.0

Notes: [a] Van body types include both dry and refrigerated vans
Counts for Headingley, Emerson and West Hawk were completed in January and February of 2010. Inkster counts occurred between 2007 and 2009.

Table 19 shows the percent proportions of 3-S2s and 3-S2s with van body types from the total observed trucks. Proportions of 3-S2s are much higher at Emerson since the truck fleet observed at this location is heavily influenced by the U.S. truck size and weight regulations. More information on Headingley, Emerson, and West Hawk can be found in Section 3.4.3. Inkster has smaller portions of 3-S2s with van body types. There are larger portions of dump body types near Winnipeg. This is likely due to snow removal since the majority of the Inkster counts were taken in the winter.

5.3 EXPOSURE ESTIMATES

This section provides a step-by-step outline of the development of exposure estimates for Turnpikes and 3-S2s, respectively. Details about developing exposure estimates for Turnpikes are provided in Regehr (2009). Jablonski et al. (2010) discuss details about developing exposure estimates for 3-S2s. This section updates 2006 Turnpike estimates, by Regehr (2006), to 2009 levels. Estimates for 3-S2s are developed from 2008 estimates, sourced from Jablonski et al. (2010), into 2009 estimates with van body types.

For the purposes of this research, exposure is expressed in terms of vehicle-kilometres of travel (VKT) by vehicle type, which is calculated by Equation 3. The VKT for vehicle type *i* is determined by multiplying AADTT for vehicle type *i* by the length (in kilometres) of the highway segment. Typically this value is annualized by multiplying by 365 days per year.

$$VKT_i = AADTT_i \text{ x } Segment\ Length \text{ x } 365\ days/year \quad (3)$$

5.3.1 Turnpike Double VKT Estimates

Figure 31 shows a schematic of the step-by-step development of exposure estimates for Turnpikes. The procedure has five steps:

1. *Assemble data sources*: This step is described in Section 5.2. The exposure estimates for Turnpikes are composed of updated from 2006 to 2009 estimates using 2009 WIM data and manual classification counts.

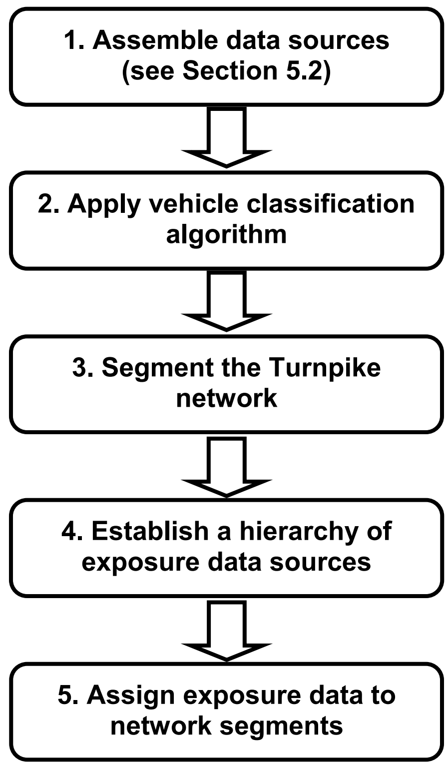


Figure 31: Development of Exposure Estimates for Turnpike Doubles

2. *Apply vehicle classification algorithm*: The vehicle classification algorithm developed by Regehr (2009) to isolate and classify Turnpikes (and other types of long trucks) is applied to WIM data. The algorithm is required because these vehicles are not typically isolated by conventional vehicle classification schemes. The algorithm, written in Structured Query Language (SQL) identifies Turnpikes with 11 different axle configurations using three criteria: vehicle wheelbase, the number of axles on the vehicle, and axle spacing.

3. *Segment the Turnpike network*: The Turnpike network is divided into segments on which exposure—in terms of volume, weight, cube, speed, and related temporal and vehicle classification distributions—is assumed homogeneous along the segment length. Segments are connected by nodes, which generally occur at:

    - the intersection of two or more highways on which Turnpike operations are permitted;
    - locations where there is a regulatory change;
    - urban area boundaries; and
    - provincial boundaries.

    Segments for Turnpikes are generally longer than segments developed for total truck traffic. This is because there are few intersecting highways in which Turnpikes operate. Trucks such as the 3-S2 will intersect many other highways on which they can operate. The segments from the 2006 estimates were maintained for 2009 exposure estimations.

4. *Establish a hierarchy of exposure data sources*: The development of a data hierarchy guides the process of integrating different data sources by formally ranking data sources according to their quality and accuracy. Regehr (2009) establishes the following hierarchy for Turnpike exposure data sources:

    - Permanent classification data obtained from WIM stations are ranked highest.
    - Sample classification data obtained from specially-configured AVCs are ranked second.
    - Estimates of Turnpike volume provided directly by industry experts are ranked third.

- Data obtained from manual classification counts are ranked lowest.

5. *Assign* exposure data to network segments: Regehr (2009) develops four techniques to assign exposure estimates to network segments:

   - Direct assignments apply data obtained from permanent classification counts, sample classification counts, and industry experts directly to the segment on which they were collected.
   - Transferring occurs when estimates based on direct assignments are assigned to adjacent segments for which no direct data source is available.
   - Intersection flow balancing techniques are applied at certain intersections where a major origin-destination pattern for Turnpikes is identified.
   - Similar highway assignments occur on segments for which exposure estimates cannot be developed directly, via transfers, or through flow balancing. These segments are assigned estimates based on assumptions on the proportional similarity of Turnpike volumes to total truck volumes.

In 2009, Turnpikes travelled a total of 13 million kilometres on the METD-Network. This represents about nine percent of the total 3-S2 and Turnpike exposure. Figure 32 shows the spatial distribution of the Turnpike Double exposure. Nearly 92 percent of Turnpike Double travel occurred on Highway 1 west of Winnipeg, six percent occurred on the Perimeter Highway, one percent occurred on Highway 1 east of Winnipeg, and one percent on Highway 75. The exposure estimates for Turnpike travel in 2006 total five million kilometres (Baumgartner et al., 2010). Turnpike VKT increased by about 60 percent from 2006 to 2009.

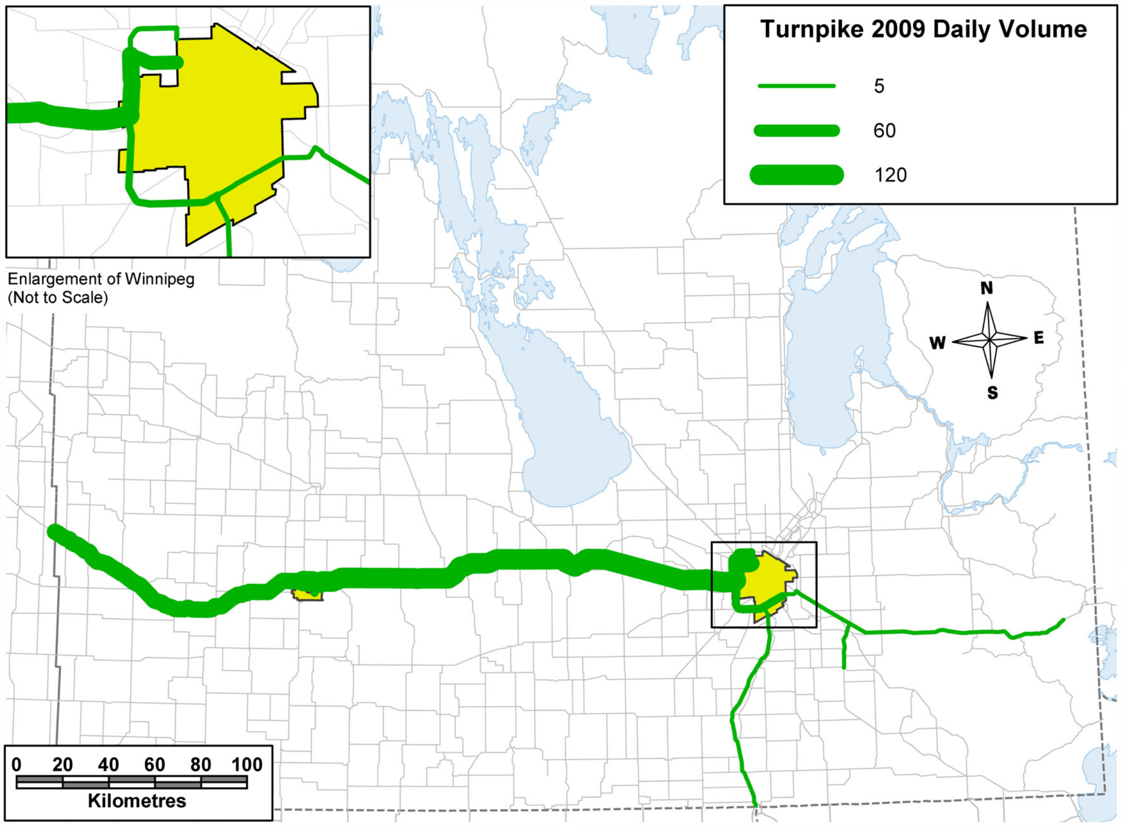


Figure 32: 2009 Turnpike Double Exposure on the METD-Network

Note: 2009 Turnpike Exposure for the METD-Network totals 13.1 million vehicle kilometres travelled.

5.3.2 Five-Axle Tractor Semitrailer VKT Estimates

Figure 33 shows a schematic of the step-by-step development of exposure estimates for Turnpikes. The procedure has six steps:

1. *Assemble data sources*: This step is described in Section 5.2. The exposure estimates for 3-S2s are representative of 2009 conditions.

2. *Calculate 3-S2 volumes from classification data*: The AADTT for 3-S2s (i.e., class 9 vehicles) is directly calculated from data collected at permanent classification stations (i.e., WIMs and AVCs). At sample classification stations, 14-hour classification data is expanded into a daily volume estimate (by vehicle class) by

establishing relationships between the sample classification station and one of five provincial truck traffic pattern groups (TTPGs). These TTPGs are based on a statistical cluster analysis which groups stations with similar temporal variations of truck volume. The cluster analysis is an algorithm that groups similar objects into a hierarchy by specific variables. In this case the variables are time of day, day of week, and monthly factors. The variables for these groups are applied to the sample count to determine AADTT by vehicle class. All sample stations used in this research are expanded using factors for TTPG 1 and TTPG 2. TTPG 1 consists of stations located on routes near Winnipeg that serve a mix of urban delivery and long-distance trips to transport a broad mix of commodities. TTPG 2 consists of stations located on routes designated as part of the National Highway System that serve long-distance trips to transport a broad mix of commodities.

3. *Segment the highway network*: The provincial highway network is divided into segments on which truck traffic exposure is assumed to be homogeneous along the segment length. Adjacent segments are connected by nodes, which occur at:

   - the intersection of two or more provincial highways;
   - urban area boundaries;
   - known truck traffic sources or sinks; and
   - changes in jurisdiction (i.e., provincial, municipal, National Parks).

   These segments are generally shorter than the segments used for Turnpike traffic because they will intersect many highways on which other 3-S2s can operate while Turnpikes will intersect few highways on which they are permitted to operate.

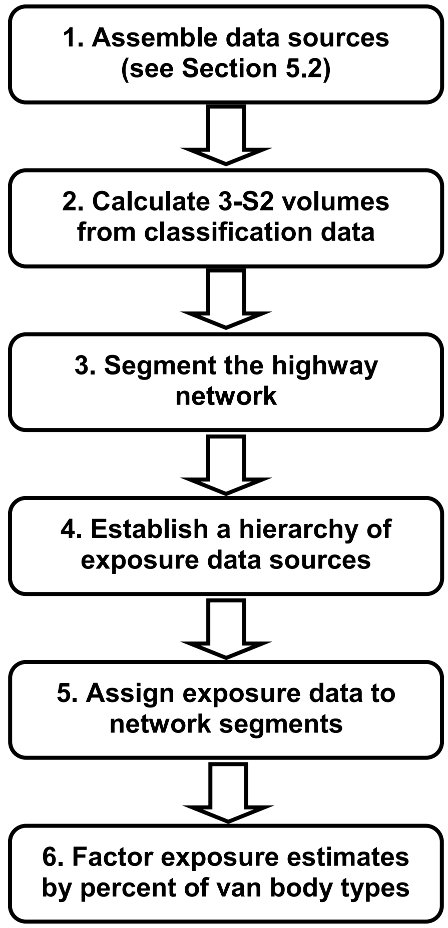


Figure 33: Development of Exposure Estimates for 3-S2s

4. *Establish a hierarchy of exposure data sources*: Jablonski et al. (2010) adopt the data hierarchy established by the National Cooperative Highway Research Program (NCHRP 2005) for the purposes of developing truck exposure estimates for pavement design. For Manitoba, this hierarchy is defined by the following ranking:

- Permanent classification data obtained from WIMs and AVCs are ranked highest.
- Sample classification data obtained from manual classification counts are ranked second.
- Classification distribution data obtained from either permanent or sample classification sites and applied to adjacent segments are ranked third.

- Classification distribution data obtained from permanent classification stations and applied to sites at which no classification data is available are ranked lowest.

5. *Assign exposure data to network segments*: Jablonski et al. (2010) assign exposure estimates to segments using the following techniques:

   - Estimates obtained from permanent and sample classification stations are assigned directly to the truck segment on which they are located. To extend the utility of this data, the homogeneity assumption is relaxed for certain segments so that the exposure estimates can also be applied to adjacent segments.

   - Exposure is estimated on certain segments located on the same highway as permanent and sample classification stations by applying the vehicle classification distribution evident at these stations to the total volume on the nearby segment.

   - On segments where no classification data is available and that are not on the same highway as permanent or sample classification stations, exposure estimates are assigned by assessing the similarity between the expected classification distribution on the segment and the classification distribution observed at one of six established truck traffic classification groups in Manitoba.

6. *Factor exposure estimates by percent of van body types*: The proportion of 3-S2s with van body types—determined from the body type surveys conducted at the Headingley, the Emerson, and West Hawk weigh scales; and the intersection of the Perimeter Highway and Inkster Boulevard—are applied to the total volume of 3-S2s estimated on the METD-Network. The proportion of van body types observed at the

Headingley Weigh Scale is assumed constant along Highway 1 between Winnipeg and Saskatchewan; the proportion of van body types observed at the Emerson Weigh Scale is assumed constant along Highway 75 between Winnipeg and Emerson; the proportion of van body types observed at West Hawk is assumed constant along Highway 1 between Winnipeg and Ontario; and the proportion of van body types observed on all legs of the intersection of the Perimeter Highway and Inkster Boulevard is assumed constant along these routes, respectively.

In 2009, 3-S2s travelled a total of 140 million kilometres on the METD-Network. This represents about 91 percent of the total 3-S2 and Turnpike exposure. Figure 34 shows the spatial distribution of the 3-S2 exposure. Nearly 69 percent of 3-S2 travel occurred on Highway 1 west of Winnipeg, nine percent occurred on the Perimeter Highway, 12 percent occurred on Highway 75, and about 10 percent occurred on Highway 1 east of Winnipeg.

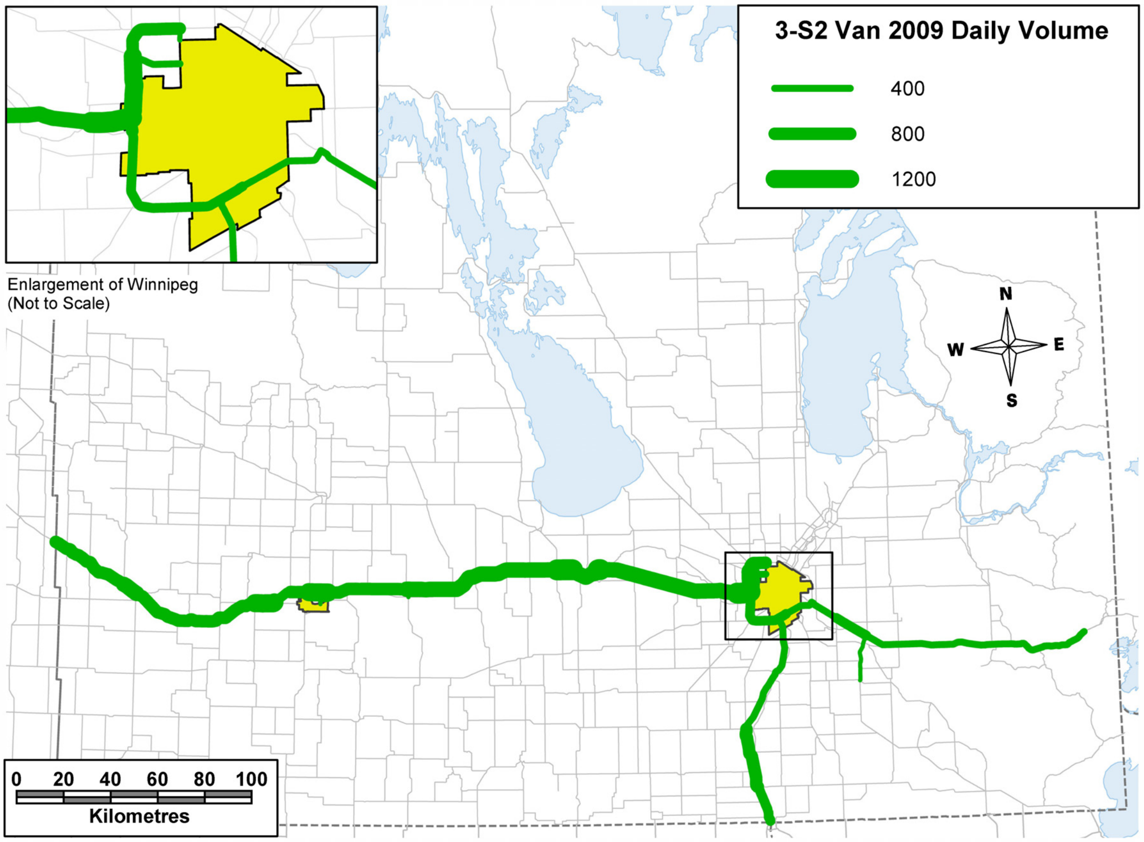


Figure 34: 2009 3-S2 Exposure on the METD-Network

Note: 2009 3-S2 Van Exposure for the METD-Network totals 139.8 million vehicle kilometres travelled.

5.4 FUEL CONSUMPTION EFFECT OF TURNPIKES

The fuel consumption effect of Turnpike Doubles on the METD-Network is determined by comparing two scenarios: (1) Scenario A, which represents the existing conditions where both 3-S2s and Turnpikes operate on the METD-Network; and (2) Scenario B, which represents the condition where there are no Turnpikes operating on the METD-Network and only 3-S2s are used to transport the same number of trailers as in Scenario A. The system-wide effect of Turnpike Doubles on fuel consumption is calculated using the following four steps:

1. Convert Turnpike Double VKT to 3-S2 VKT: Since one Turnpike effectively replaces two 3-S2s, the Turnpike VKT in Scenario A is doubled to determine the 3-S2 VKT for Scenario B. This assumes that the same quantity of 16.2-metre trailers will be moved.

2. Multiply Scenario B VKT by 3-S2 fuel consumption rate: Multiply the VKT from Step 1 by the average fuel consumption rate of a 3-S2 (42.2 litres per 100 kilometres).

3. Determine total fuel consumed for each scenario: The total fuel consumed in Scenario A is determined by summing the product of the VKT and fuel consumption rates for 3-S2s and Turnpikes (55.7 litres per 100 kilometres). The total fuel consumed in Scenario B is determined in Step 2.

4. Determine the difference between the scenarios: Subtract the total fuel consumed in Scenario A from the fuel consumed in Scenario B.

Table 20 reveals that the use of Turnpike Doubles (at 2009 levels) reduced fuel consumption by an estimated 3.8 million litres on the METD-Network. This is a five percent reduction in fuel consumption for an eight percent reduction in VKT.

Table 20: Effect of Turnpike Double on Fuel Consumption

Scenario	3-S2 VKT [a] (million)	Turnpike VKT (million)	Total VKT (million)	Total Fuel Consumption (million litres)
A [b]	139.8	13.1	152.9	66.3
B [c]	166.0	-	166.0	70.1
Difference	26.2	13.1	13.1	3.8
% Difference	16%	-	8%	5%

Notes: [a] 3-S2 VKT is for dry and refrigerated van trailers.
[b] Scenario A represents the case where both 3-S2s and Turnpikes operate.
[c] Scenario B represents the case where Turnpikes do not operate and 3-S2s must move the same amount of freight.
Estimates are for 2009 on the METD-Network.

The scenario analysis is extended to the other fuel consumption models developed in Chapter 4 for fuel consumption by average payload weight and by cubic capacity. These fuel consumption rates are:

- *Average payload weight*: 3.4 litres per tonne-100 kilometres for 3-S2s and 2.6 litres per tonne-100 kilometres for Turnpikes (see Section 4.2.3).
- *Cubic Capacity*: 0.81 litres per pallet-100 kilometres for 3-S2s and 0.54 litres per pallet-100 kilometres for Turnpikes (see Section 4.2.4).

Table 21 shows that Turnpikes (at 2009 levels) reduced the fuel consumption by average payload weight by 0.5 million litres per tonne of freight moved on the METD-Network. This is approximately a nine percent reduction in fuel consumed per tonne of freight for an eight percent reduction in VKT. The table further identifies that a Turnpike can reduce fuel consumption by 0.1 million litres per pallet of freight moved on the METD-Network. This is an approximate eight percent reduction in fuel consumption per pallet for an eight percent reduction in VKT.

Table 21: Effect of Turnpike Double on Fuel Consumption by Average Payload and Cubic Capacity

Scenario	3-S2 VKT [a] (million)	Turnpike VKT (million)	Fuel Consumption by: Average Payload Weight (million litres per tonne)	Fuel Consumption by: Cubic Capacity (million litres per pallet)
A [b]	139.8	13.1	5.1	1.2
B [c]	166.0	-	5.6	1.3
Difference	26.2	13.1	0.5	0.1
% Difference	16%	-	9%	8%

Notes: [a] 3-S2 VKT is for dry and refrigerated van trailers.
[b] Scenario A represents the case where both 3-S2s and Turnpikes operate.
[c] Scenario B represents the case where Turnpikes do not operate and 3-S2s must move the same amount of freight.
Estimates are for 2009 on the METD-Network.

5.5 CARBON DIOXIDE EMISSIONS EFFECT OF TURNPIKE DOUBLES

The key types of air pollutants relevant to heavy truck transportation are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), and sulphur oxides (SO_x). CO_2 emissions are relatively constant across different engine years and types, and are directly related to fuel consumption. SO_x emissions rates are determined by fuel standards and are thereby, also directly related to fuel consumption. CH_4, N_2O, NO_x, PM, CO, and HC vary by engine year as a result of changes in engine emissions standards. Emission rates for the other pollutants are only available in terms of mass per kilometre travelled. Many emission modelling software programs such as MOBILE6 and EFMAC2007 are based on engine test data. This required emission factors to be converted based on fuel density (grams per mile). The large variation in GVW, transmission types, fuel economy, and horsepower ratings develop high uncertainties (NCFRP, 2010).

Environment Canada (2010b) provides CO_2 emission rate of 2663 grams per litre of diesel fuel for a Heavy Duty Diesel Vehicle. Although CO_2 emission rates in grams per kilometre are readily-available, they do not differentiate the performance of 3-S2s versus Turnpike Doubles. Since determining this performance difference is the objective of this research, a CO_2 emission rate in grams per litre is used instead.

The emissions impact of Turnpike Doubles on the METD-Network is determined similarly to the fuel consumption impact (using the same Scenarios A and B), with an additional step to convert fuel consumption into emissions. This method utilizes emission rates of

CO_2 in mass per volume of fuel consumed. The system-wide emissions impact of Turnpike Doubles is calculated using the following three steps:

1. Multiply Scenario B fuel consumption by the CO_2 emission rate: Multiply fuel consumption by the CO_2 emission rate of 2663 grams of CO_2 per litre of fuel consumed.

2. Determine total CO_2 emissions for each scenario: The total CO_2 emissions in Scenario A are determined by summing the product of the VKT and fuel consumption rates for each vehicle type and then converting it into CO_2 using the CO_2 emissions rate. The total CO_2 emissions in Scenario B are determined in Step 3.

3. Determine the difference between the scenarios: Subtract the total CO_2 emissions in Scenario A from the total CO_2 emissions in Scenario B.

Table 22 shows the CO_2 emissions by fuel consumption rates (in Table 20) and fuel consumption by average payload weight and by cubic capacity. The use of Turnpikes (at 2009 levels) reduced CO_2 emissions by an estimated 10 million kilograms on the METD-Network. This is a five percent reduction for an eight percent reduction in VKT. On an average payload weight case, Turnpikes reduced CO_2 emissions by an estimated 1.3 million kilograms per tonne of freight. The CO_2 emissions of Turnpikes by cubic capacity metric can reduce 0.3 million kilograms of CO_2 per pallet moved.

Table 22: Effect of Turnpike Double on CO_2 Emissions

Scenario	Total VKT (million)	Total CO_2 Emissions (million kilograms)	CO_2 Emissions by:	
			Average Payload Weight (million kilograms per tonne)	Cubic Capacity (million kilograms per pallet)
A [a]	152.9	176.6	13.6	3.2
B [b]	166.0	186.7	14.9	3.5
Difference	13.1	10.1	1.3	0.3
% Difference	8%	5%	9%	8%

Notes: [a] Scenario A represents the case where both 3-S2s and Turnpikes operate.
[b] Scenario B represents the case where Turnpikes do not operate and 3-S2s must move the same amount of freight.
Estimates are for 2009 on the METD-Network.

Since CO_2 emissions are directly related to fuel consumption, the percent reduction of CO_2 emissions is the same value as the percent savings in fuel consumed.

5.6 IMPLICATIONS TO TRANSPORTATION ENGINEERING

The results of the scenario analysis indicate that the operation of Turnpikes can reduce the trips that would otherwise be made by two 3-S2s and therefore, the resources required to do so. If Turnpikes were to replace all 3-S2s with van trailers, then the maximum VKT reduction would be 50 percent since one Turnpike can move twice the trailers as a 3-S2. On average, operating a Turnpike in place of two 3-S2s can save 28.7 litres per 100 kilometres of travel (a 34 percent savings). At this rate, Turnpikes can save a maximum of 34 percent in fuel consumed if they replace all the 3-S2 vans operating on the Turnpike network. At 2009 levels of VKT, this would reduce fuel consumption by approximately 24 million litres than if all the freight were moved by 3-S2s.

The increasing concern with energy security and climate change from the public and governments puts transportation engineers in a position to design, develop, and implement solutions that reduce resource consumption and are environmentally and economically sustainable. Since the operation of Turnpikes directly saves the carrier in fuel consumption costs, their presence in the Canadian Prairie region will likely continue to grow and transportation engineers will need to resolve challenges in terms of safety, infrastructure design and maintenance, traffic operations and fuel consumption and emissions.

6. CONCLUSIONS

The research analyzes fuel consumption and emissions of Turnpike double trailer combinations on a regional network in the Canadian Prairie region. The research: (1) establishes current benchmarks for fuel consumption of Turnpikes and five-axle tractor semitrailers with van body types; (2) designs, develops, and applies fuel consumption models for these vehicle types; (3) establishes an understanding in current operating characteristics of Turnpikes in the region; and (4) estimates their system-wide effects in terms of fuel consumption and carbon dioxide emissions in Manitoba by applying the developed models.

This chapter summarizes the findings of the research in terms of the Turnpike transportation system characteristics, fuel consumption models of Turnpikes and 3-S2s, and system-wide fuel consumption and carbon dioxide emission effects of Turnpikes operating in the Canadian Prairie region. Finally, this chapter makes recommendations for future research are provided in the final section.

6.1 LITERATURE REVIEW

The literature review reveals the following:

- The primary pollutants emitted by diesel internal-combustion engines are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), sulphur oxides (SO_x), and hydrocarbons (HC). These pollutants create greenhouse gases (GHGs), are detrimental to human health, affect the health of natural systems, and contribute to infrastructure deterioration. In Canada, GHG emissions by heavy trucks have increased by 161 percent between 1990 and 2007.

- Trucks that carry larger payloads (in terms of weight and cube) are more efficient (per weight-distance or cube-distance) than smaller, lighter trucks. Therefore, the liberalization of truck size and weight limits has the potential to yield environmental benefits. Studies which focus specifically on Turnpikes indicate that these vehicles provide fuel consumption and emissions benefits relative to the vehicles they replace.

- The literature identifies the use of a variety of metrics for measuring fuel consumption and emissions performance by heavy trucks. Metrics that incorporate cargo weight and/or cube enable more realistic comparisons between different types of trucking operations.

- Aerodynamic devices can be designed into tractor semitrailers and/or attached to the vehicle. Specific technologies identified in the literature to reduce aerodynamic drag are: cab-roof fairings, cab roof deflectors, trailer side fairings, rear fairings, fuel tank fairings, tractor/trailer gap fairings, aerodynamic tractors, pneumatic blowing, and cab side extenders.

- Tire technologies to reduce rolling resistance include: (1) wide-based tires (or super singles), which can replace dual tires thereby reducing tare weight, engine load and fuel consumption; (2) low rolling resistance tires; and (3) improved tire inflation and monitoring with automatic tire inflation (ATI) systems and nitrogen inflation.

- Technological options for reducing tractor and trailer tare weight include aluminum wheels, axle hubs, and tractor and trailer frames.

- The implementation of auxiliary power units (APUs) and the development and use of truck stop electrification reduce the fuel consumed and emissions produced by idling trucks.

- Operating speeds can be reduced for heavy duty fleets by speed governors installed in the tractor or by driver training coupled with incentives programs.

- Strategies that reduce fuel consumption by targeting driver behaviour include: idle time reduction, speed limiting, adjustment of shifting technique, modification of acceleration practice, route choice, accessory load reduction, and decreasing the number of stops. New drive train technologies are less sensitive to driver errors; in addition, real-time driver monitoring allows fleets to maintain a controlled operational envelope.

6.2 CHARACTERIZATION OF THE TRANSPORTATION SYSTEM

The characterization of the transportation system reveals the following:

- As of January 1, 2011, the Turnpike Double network in the Canadian Prairie region measures 4,100 centreline-kilometres.

- Regulatory prohibitions of Turnpike operations in British Colombia, Ontario, and the United States render certain sections of the Canadian Prairie region's Turnpike Double network to be operationally impractical.

- Heavy truck emission regulations are regulated at the Federal government level in Canada and have been harmonized with the U.S. EPA since 1988. These have targeted: (1) engine manufacturers for NO_x, PM, HC, and CO emissions; (2) fuel suppliers for sulphur content to restrict SO_x emissions; (3) and are now targeting vehicle manufacturers for GHG emissions of CO_2, CH_4, N_2O, and HFCs.

- WIM data on Highway 1 between Winnipeg and Brandon at MacGregor, MB show a growth of 78 percent in Turnpike volumes from 2005 to 2009. This is partially attributed to: (1) the completion of the divided highway between Virden, MB and Moosomin, SK, which completed the link for Canadian Prairie regional Turnpike Double network; and (2) an economic recession during 2008 and 2009 that caused trucking companies to increase their operation of Turnpikes in order to remain competitive (as indicated by carriers in the Canadian Prairie region).

- Weigh scale surveys were conducted at three locations in Manitoba for a week in January and February, 2010 to identify axle weight characteristics of Turnpikes and 3-S2s with van trailers (dry and refrigerated). The surveys counted a total of 8,431 articulated trucks and were conducted at the Headingley weigh scale west of Winnipeg, the Emerson weigh scale at the Canada-U.S. border, and the West Hawk weigh scale near the Manitoba-Ontario border.

- The combined weight of Turnpike drive and lead trailer axles are approximately seven tonnes heavier than the combined weight of the rear trailer’s axles. This is in accordance with the Turnpike permitting regulations, which state that the lead trailer must be heavier than the rear trailer.

- 3-S2s with van trailers represent approximately 45, 46, and 48 percent of the articulated truck fleet samples at the Headingley, Emerson, and West Hawk weigh scales, respectively.
- Tandem axle weights on 3-S2s (with van trailers) and Turnpike lead trailers average approximately 11 tonnes for a 17 tonne limit throughout the three stations. This is evidence of cube-out freight in both of these vehicle types.

6.3 DEVELOPMENT OF FUEL CONSUMPTION MODELS

The development of fuel models reveals the following:

- Canadian Prairie region-based carriers were contacted for fuel consumption data and to complete a questionnaire. These companies operate a combined fleet of 2,200 tractors and 6,000 trailers. The responses revealed that these companies had a combined increase in Turnpike Double travel (from 2007 to 2009) in the Canadian Prairie Region of 44 percent after the twinning of the Trans Canada Highway was completed between Winnipeg and Regina in 2007.
- The analysis of the normalized fuel consumption data determines average fuel consumption rates of 42.2 and 55.7 litres per 100 kilometres of travel for 3-S2s and Turnpike Doubles, respectively. On average, Turnpikes operating in place of two 3-S2s save a carrier 28.7 litres per 100 kilometres of travel (a 34 percent savings).
- Seasonal variations indicate higher fuel consumption in the winter months in both vehicle configurations. Winter fuel consumption savings from operating a

Turnpike in place of two 3-S2s is about 30.7 litres per 100 kilometres. About 28.8 litres fuel are saved per 100 kilometres of summer operations.

- Metrics that incorporate a freight task such as fuel consumed per tonne-kilometre or per pallet-kilometre indicate the fuel consumption benefits of Turnpikes. 3-S2s consume 3.4 litres per tonne-100 kilometres and Turnpikes consume 2.6 litres per tonne-100 kilometre, saving 24 percent on a tonne-kilometre basis. On a pallet-kilometre basis, 3-S2s consume 0.81 litres per pallet-100 kilometre and Turnpike Doubles consume 0.54 litres per pallet-100 kilometre, a savings of 33 percent.

6.4 ESTIMATING SYSTEM-WIDE EFFECTS OF TURNPIKE DOUBLES

An analysis network in Manitoba is used to estimate the system-wide effect of Turnpikes in Manitoba on 630 centreline-kilometres, defined for 2009 Turnpike exposure, and is referred to as the Manitoba Effective Turnpike Double Network (METD-Network).

The fuel consumption and CO_2 emissions impact of Turnpike Doubles on the METD-Network is determined by comparing two scenarios:

(1) Scenario A, which represents the existing conditions where both 3-S2s and Turnpikes operate on the METD-Network; and

(2) Scenario B, which represents the condition where there are no Turnpikes operating on the METD-Network and only 3-S2s are used to transport the same number of trailers as in Scenario A.

The use of Turnpike Doubles (at 2009 levels) reduced:

- fuel consumption by an estimated: 3.8 million litres and CO_2 emissions by an estimated 10.1 million kilograms on the METD-Network. This is a five percent reduction in fuel consumption and emissions for an eight percent reduction in VKT.

- fuel consumption by average payload weight by 0.5 million litres per tonne and CO_2 emissions by an estimated 1.3 million kilograms per tonne of freight moved by on the METD-Network. This is approximately a nine percent reduction in fuel consumed and CO_2 emissions per tonne of freight for an eight percent reduction in VKT.

- fuel consumption by cubic capacity by 0.1 million litres and per pallet and CO_2 emissions by an estimated 0.3 million kilograms per pallet of freight moved on the METD-Network. This is an approximate eight percent reduction in fuel consumption and CO_2 emissions per pallet for an eight percent reduction in VKT.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

This research identifies the need for future research to:

- develop heavy duty diesel truck engine emission factors (by engine year) for different tractor semitrailers combinations and axle configurations in Canada for NO_x, PM, CO, HC, SO_x, and CH_4. This would include Turnpike Doubles. This would provide better tools to assess the emissions rates of different vehicle types operating on Canadian highways.

- acquire and compare fuel consumption data for Turnpikes and 3-S2s with accurate GVW data in order to compare the relationship of fuel consumption and GVW between the two vehicle types.

- analyze the effect of different vehicle technologies on fuel consumption of Turnpikes and 3-S2s. These technologies would include devices to reduce aerodynamic drag and rolling resistance.

- study the payload operations of cube-out freight for Turnpikes and 3-S2s in the Canadian Prairie region.

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January 10, 2011

To Jennifer Lee Malzer

I am requesting permission to include in my graduate thesis, entitled *Fuel Consumption and Emissions of Turnpike Doubles in the Canadian Prairie Region,* the following material:

Figure 5.2: Sensitivity of Fuel Use Changes in TKT and GVW

Obtained from an electronic copy of the original microfilm manuscript:

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2 messages

Tom Baumgartner <umbaumg1@cc.umanitoba.ca> **Mon, Jan 10, 2011 at 11:47 AM**

To: Jen.Malzer@calgary.ca

Hi Jen,

I am completing my Master of Science in Civil Engineering on "Fuel Consumption and Emissions of Turnpike Doubles in the Canadian Prairie Region". I reference your thesis in my literature search and would like to use one of the graphs you created on the sensitivity of increases in GVW and TKT on fuel consumption. This is Figure 5.2: Sensitivity of Fuel Use Changes in TKT and GVW on page 51 of your thesis on "Aspects of Energy Use and Emissions by Heavy Trucks" (2005).

I have attached the image that I am referring to and a letter requesting use of the image in this email. You don't need to sign the letter, your email response will suffice. I will PDF the email and add it in an appendix next to the permission letter. Your contact information will be blacked out.

Thank you.

Sincerely,

Thomas Baumgartner, EIT
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University of Manitoba
Transport Information Group
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2 attachments

Sensitivity of Fuel Use to Changes in TKT & GVW.png
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Malzer, Jen <Jen.Malzer@calgary.ca> **Mon, Jan 10, 2011 at 12:08 PM**

To: Tom Baumgartner <umbaumg1@cc.umanitoba.ca>

Hi Tom,
Of course, please do use the figure – that's the whole point of doing research!

Good luck & best regards,
Jen.

Jen Malzer, P.Eng, MSc.
Senior Transit Planner
Calgary Transit
The City of Calgary | Mail Code #8124
T 403.268.2071 | **F** 403.268.1874 | www.calgary.ca
Floor 7, Municipal Building - H20, 800 Macleod Trail S.E.
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APPENDIX B: MOTOR CARRIER SURVEY QUESTIONNAIRE

Motor Carrier Survey on Fuel Use and Emissions

****The information you provide here will be kept strictly confidential****

The following questions are in regards to fuel consumption and emissions from operating Turnpike Doubles and five-axle tractor semitrailers for vans and refrigerated trailer movements. You are assured that the information you provide will be kept strictly confidential.

---

1. Fleet size:

Number of tractors	
Number of trailers	

2. How many kilometres of travel did your company operate in the Canadian Prairie Region for the categories shown in the table below:

YEAR	**TURNPIKE DOUBLES** (kms in the prairie region)	**5-AXLE TRACTOR SEMIS** (kms in the prairie region)	**Total km of travel by full fleet in the Prairies**	**Total km of travel by full fleet in North America**
2009				
2008				
2007				

PLEASE GO TO THE NEXT PAGE

3. What types of fuel efficiency technologies do you use? Please indicate the number of tractors and trailers on which each of these technologies are used.

Technology	**No. of Tractors (or %)**	**No. of Trailers (or %)**
Aerodynamic Devices [i.e. Trailer gap reducer, boat tail (rear trailer fairing), side skirts, and so on]		
Automatic Tire Inflation System		
Nitrogen Inflation		
Super Single (Wide) Tires		
Low-Weight Aluminum Wheels		
Idle Reducing Technology [e.g Alternative Power Units, cab heaters and coolers, and so on] Please specify: ____________________________________		
Other (please specify)		

4. What types of emission reduction technologies do you use apart from fuel efficiency technologies? Please indicate the number of units using these technologies in your fleet.

Technology	**No. of Tractors (or %)**
Diesel Particulate Filters	
Diesel Oxidation Catalyst	
Urea-Based Selective Catalytic Reduction	
Other (please specify):______________________________	

Additional Comments:

____

____

PLEASE GO TO THE NEXT PAGE

1. What is the major reason for your company's use of emission reducing technologies (i.e. government legislation, customer requirement, other)?

____

____

2. Does your company encourage drivers to reduce their speed? If so, to what speed?

____

3. Does your company utilize speed governors? If so, to what speed limit?

____

4. Does your company employ driver training, incentive and/or monitoring programs? Please describe the program and comment on your experience to date regarding its performance.

____

____

____

END OF SURVEY

APPENDIX C: WEIGH SCALE CHARTS

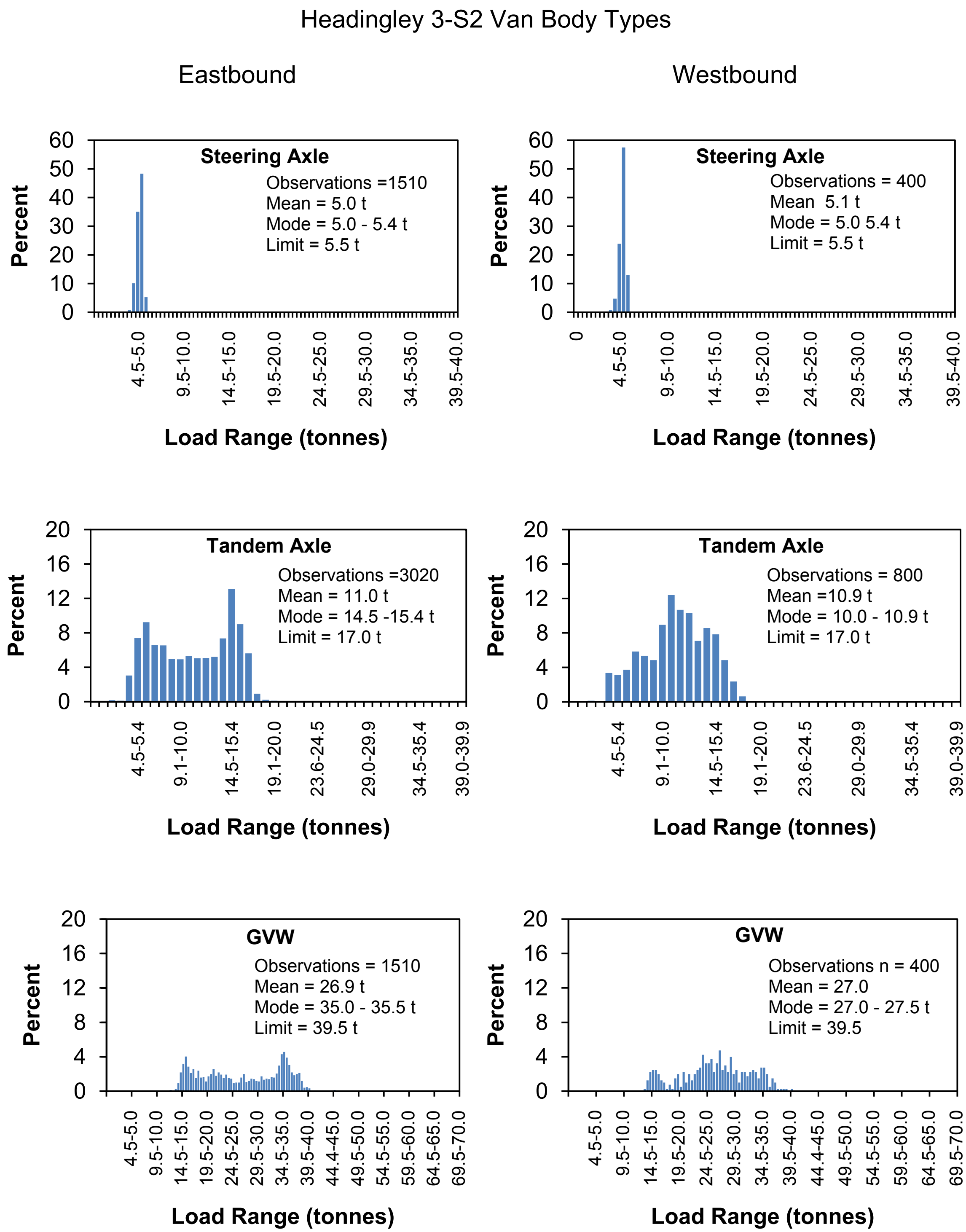


Figure 35: Headingley 3-S2 Van Axle Load Spectra Histogram

Notes: Van body types include both dry and refrigerated vans.
Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

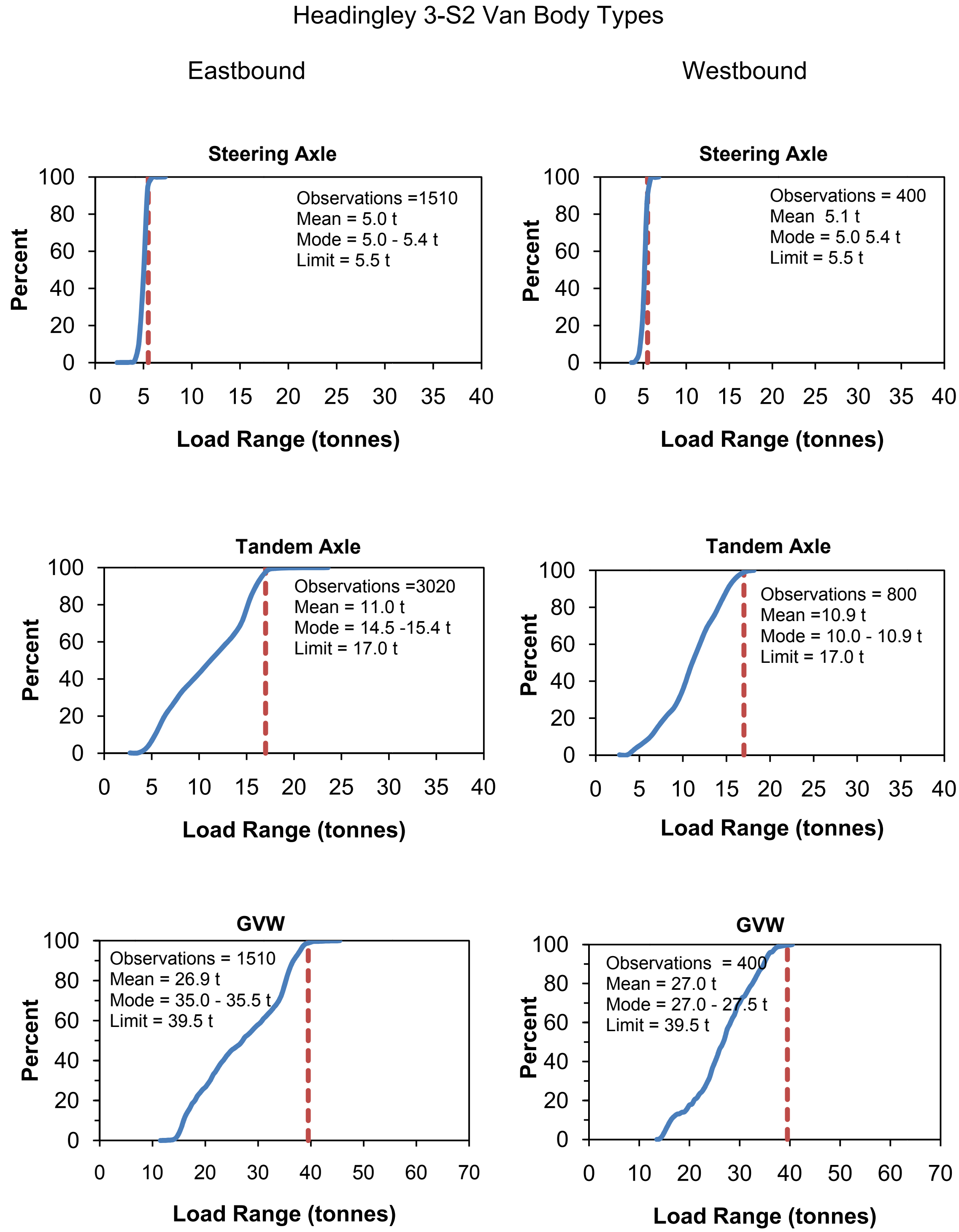


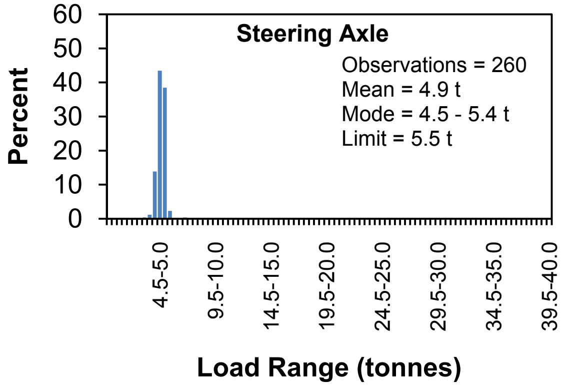
Figure 36: Headingley 3-S2 Van Axle Load Spectra Cumulative Distribution

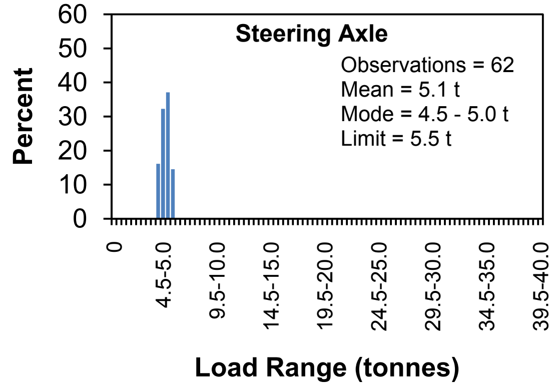
Notes: Van body types include both dry and refrigerated vans.
Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

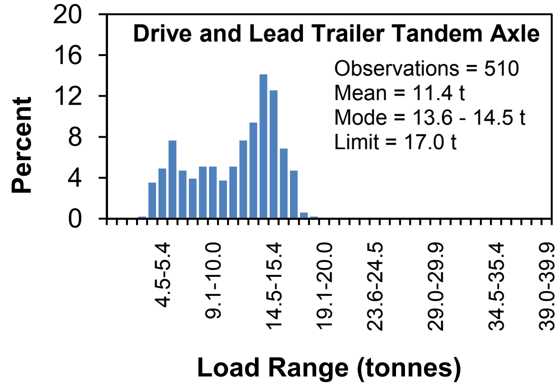
Headingley Turnpike Double

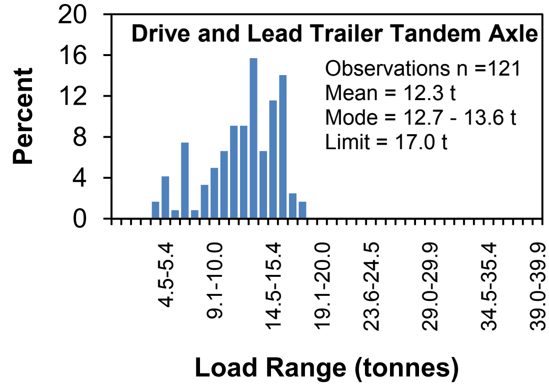
Eastbound

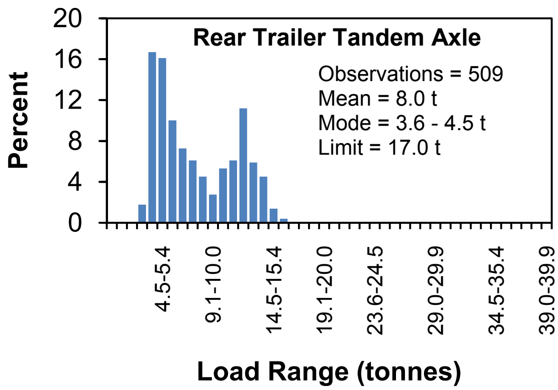
Westbound

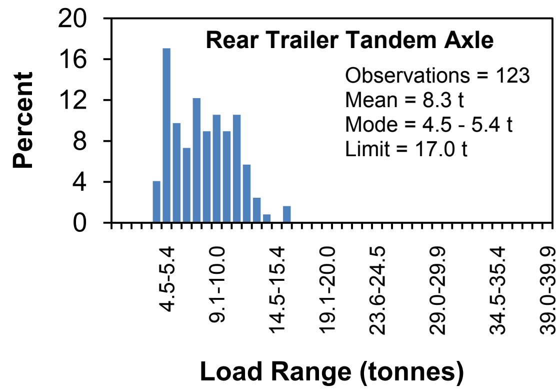




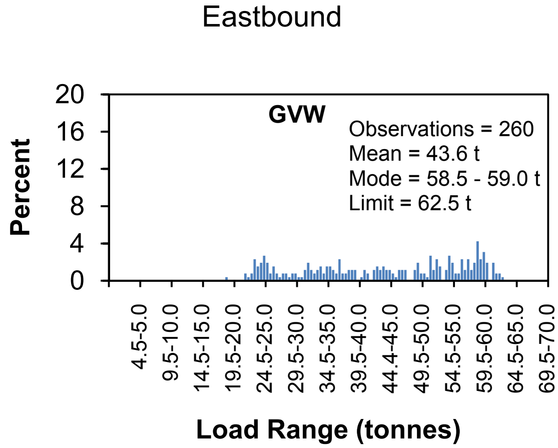








Headingley Turnpike Double



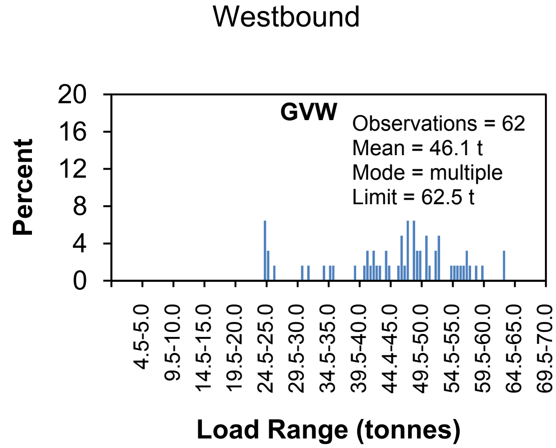


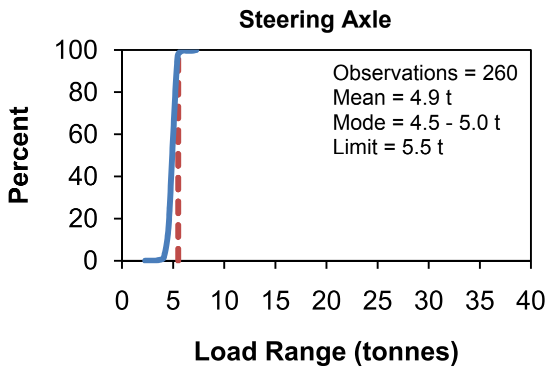
Figure 37: Headingley Turnpike Axle Load Spectra Histogram

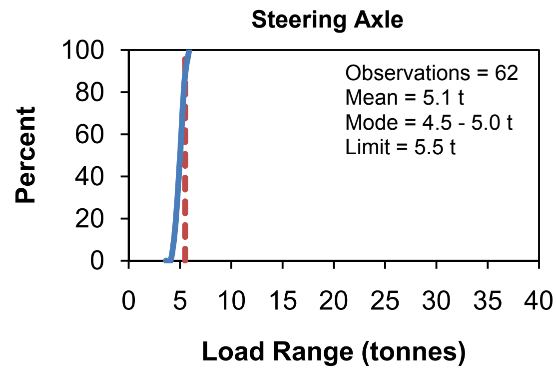
Notes: Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

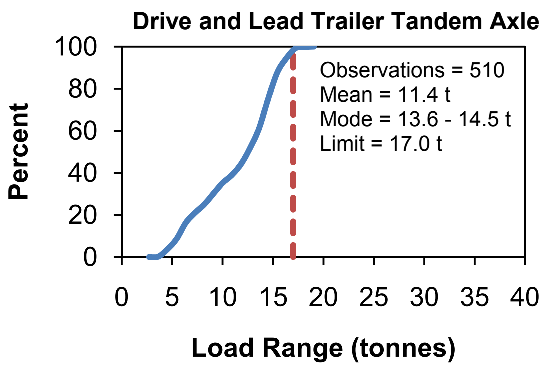
Headingley Turnpike Double

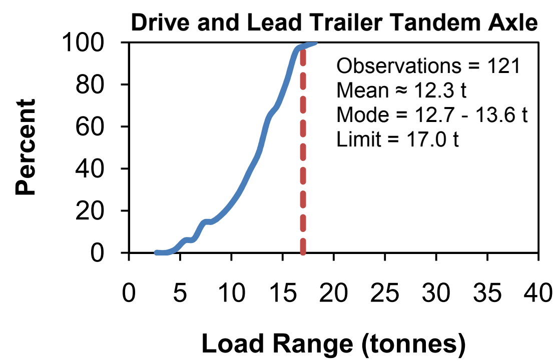
Eastbound

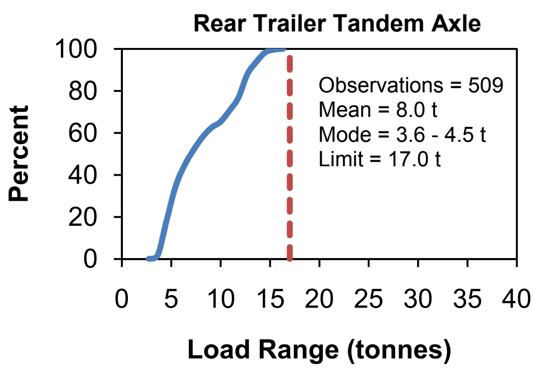
Westbound

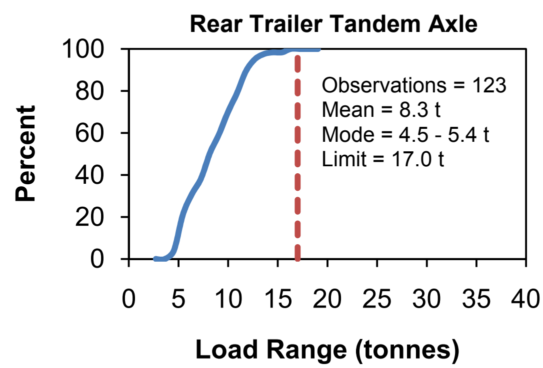












Headingley Turnpike Double

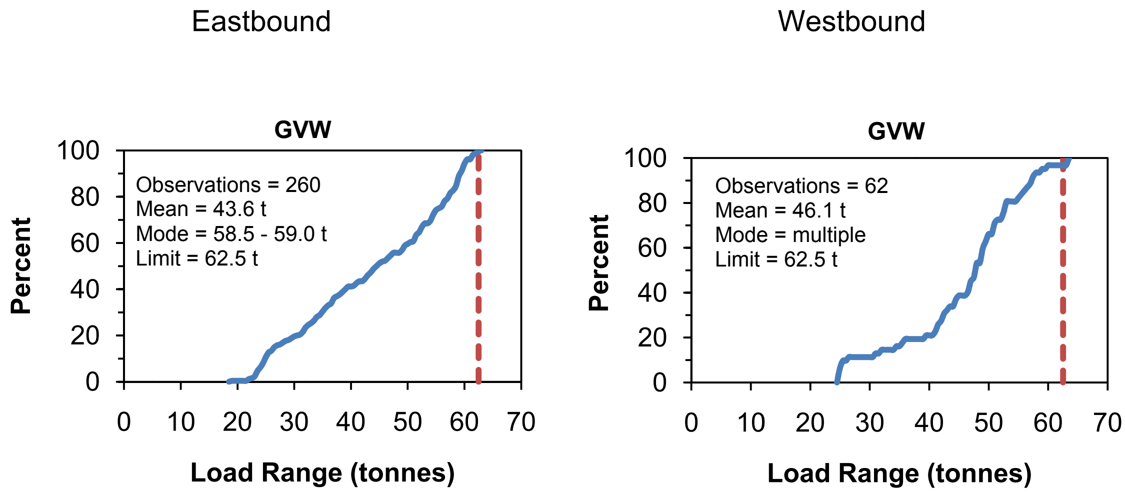


Figure 38: Headingley Turnpike Axle Load Spectra Cumulative Distribution

Notes: Data was collected from Tuesday, January 26, 2010 to Tuesday, February 2, 2010.

Emerson 3-S2 Van Body Types

Histogram | Cumulative Distribution

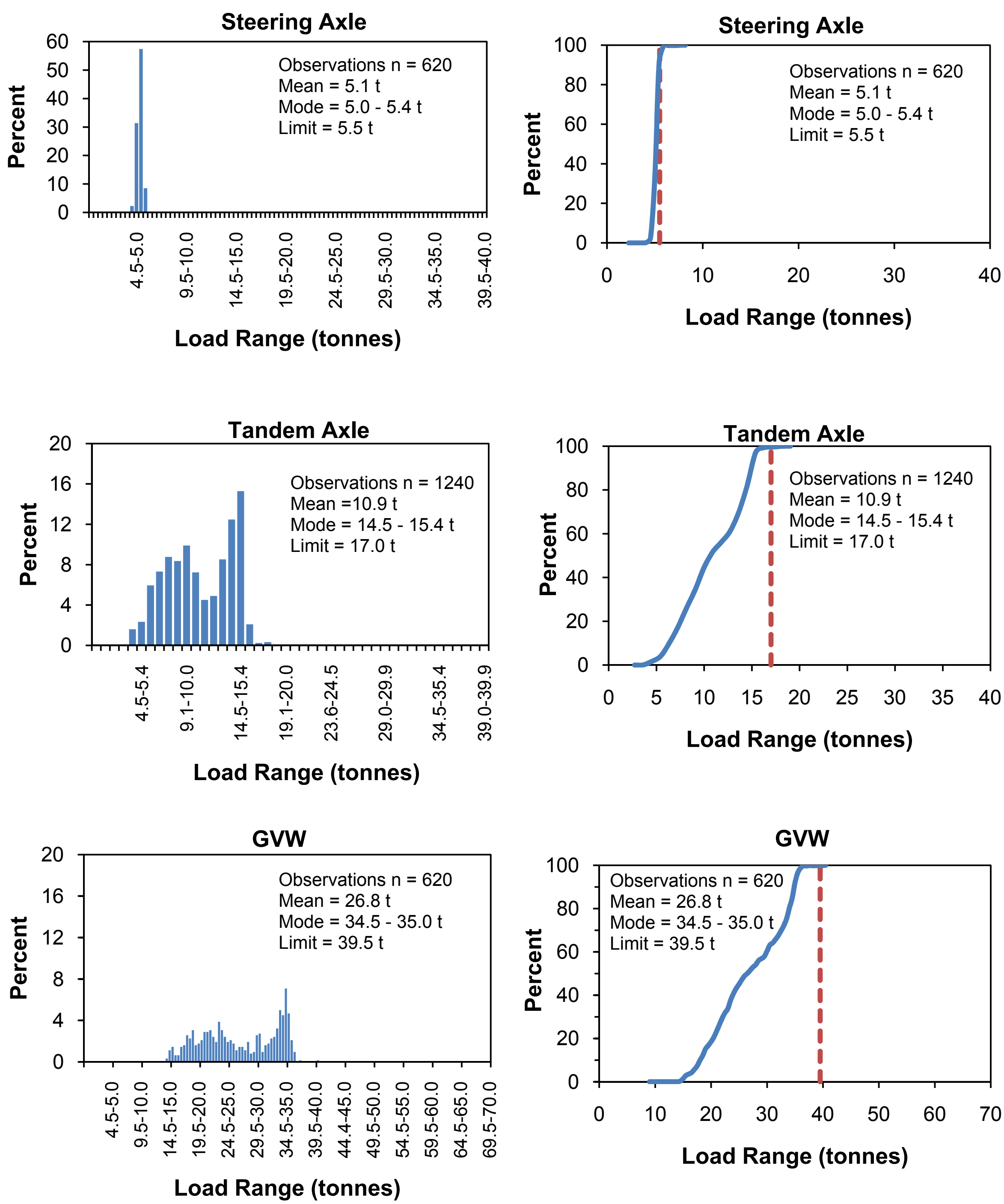


Figure 39: Emerson 3-S2 Van Axle Load Spectra

Note: Van body types include both dry and refrigerated vans.
Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

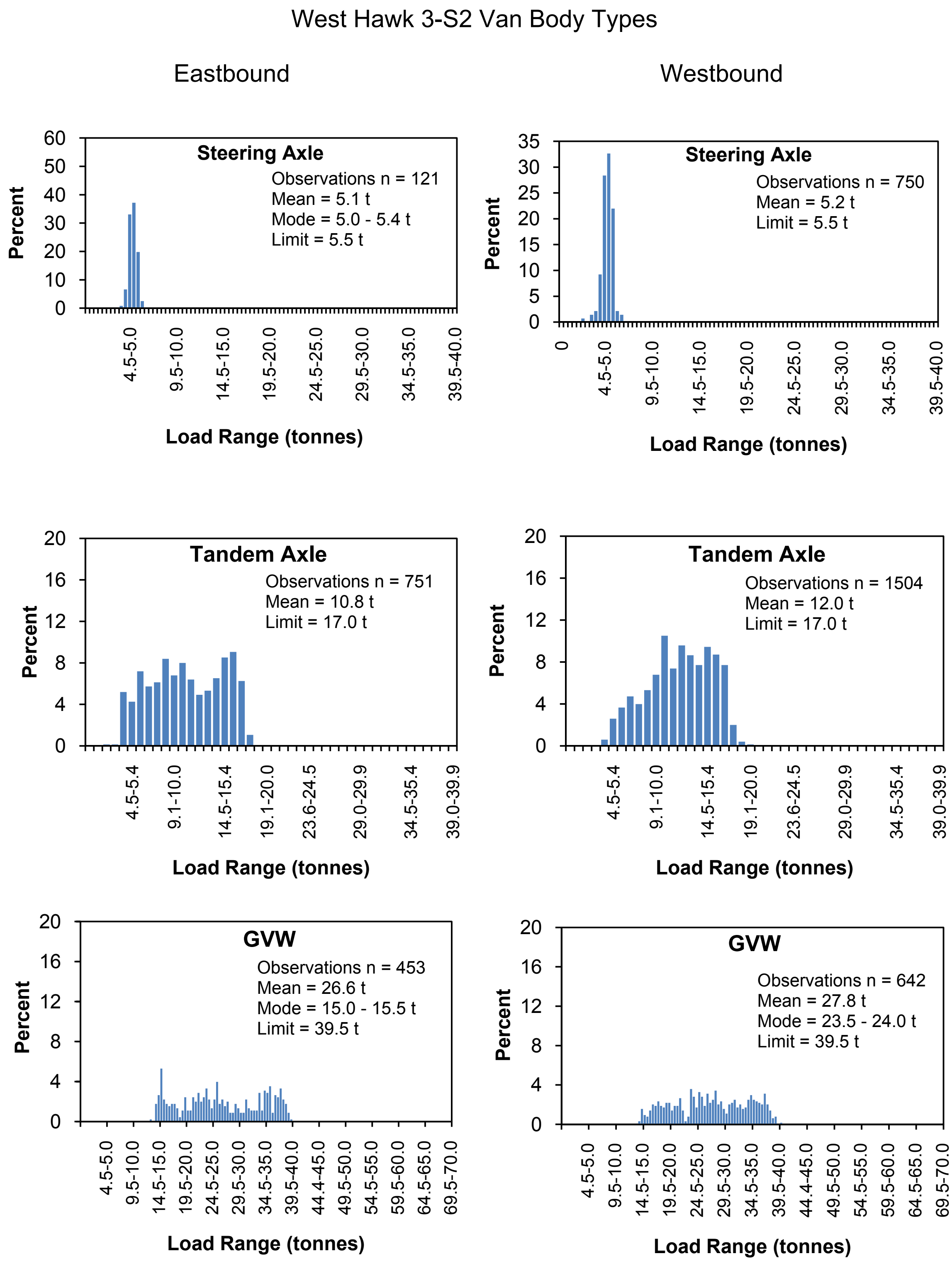


Figure 40: West Hawk 3-S2 Van Axle Load Spectra Histogram

Note: Van body types include both dry and refrigerated vans.
Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

West Hawk 3-S2 Van Body Types

Eastbound

Westbound

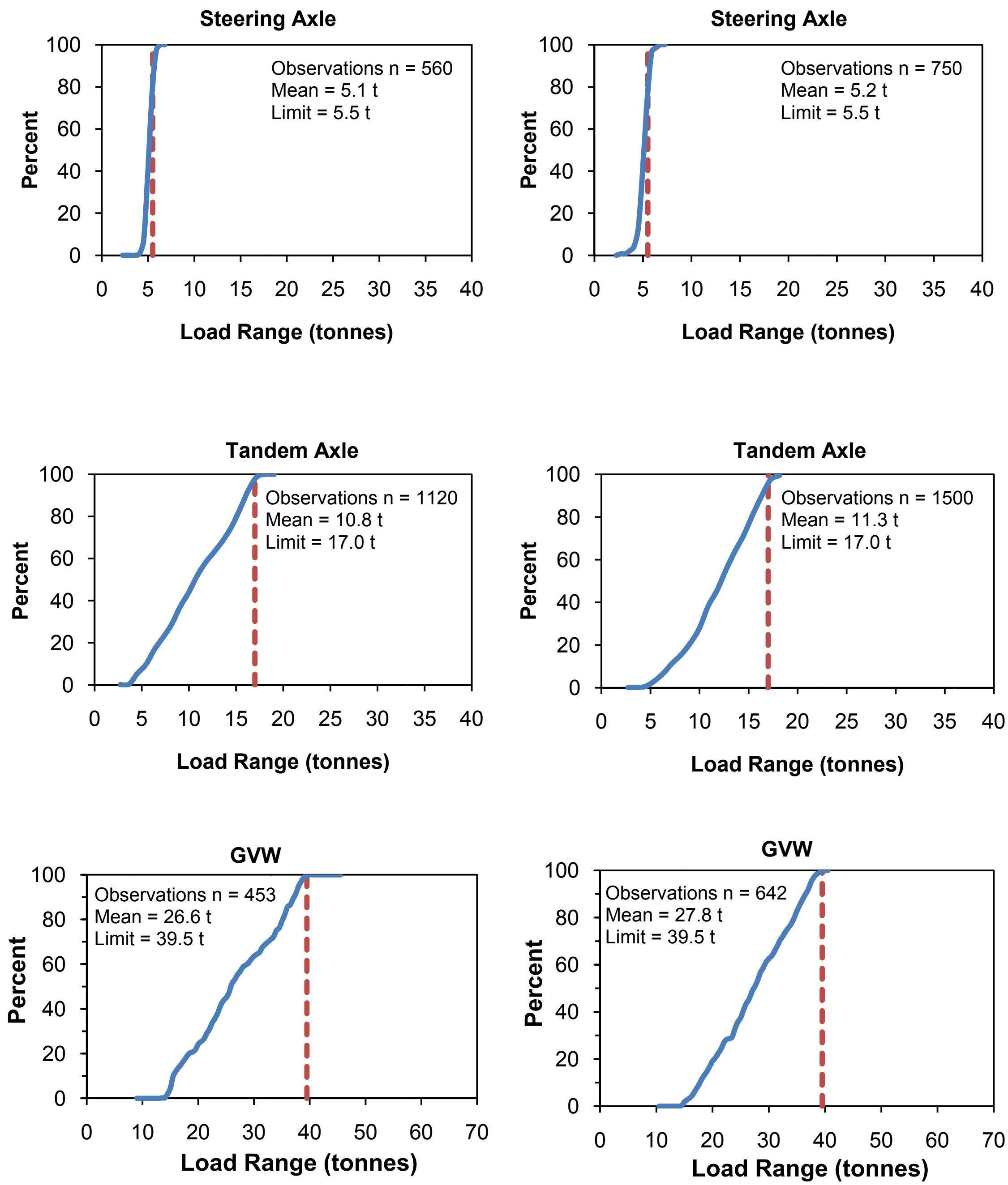


Figure 41: West Hawk 3-S2 Van Axle Load Spectra Cumulative Distribution

Note: Van body types include both dry and refrigerated vans.
Data was collected from Monday, February 15, 2010 to Friday, February 19, 2010.

APPENDIX D: EXPOSURE DATA SOURCES

TURNPIKE DOUBLE EXPOSURE DATA SOURCES

Table 23: Permanent Weigh-In-Motion Stations

Station Number	Station Name	Location
M61	Brokenhead	PTH 1, 8.9 km East of PR 302
M63	Glenlea	PTH 75, 5.1 km South of PR 210
M64	Symington	PTH 100, West of Symington Road
M65	MacGregor	PTH 1, 7.0 km West of PR 350
S62	Fleming	PTH 1, West of Saskatchewan-Manitoba Border

Note: WIM station numbers starting with "M" are provided by MHTIS. Stations beginning with "S" are provided by Saskatchewan Highways and Infrastructure.

Table 24: Manual Classification Count

Location	Date	Day of Week	Time of Day
Inkster Blvd (PR 221) and north Perimeter Hwy (PTH 101)	26-Feb-09	Thursday	1900-2300
	28-Feb-09	Saturday	0530-1000

Note: Count performed by UMTIG

FIVE AXLE TRACTOR SEMITRAILER EXPOSURE DATA SOURCES

Table 25: Permanent Classification Count Stations

Station	Type	Location	Data Year
9	AVC	PTH 75, 1.1 km North of PR 247	2009
19	AVC	PTH 1, 1.6 km East of PR 207	2008
25	AVC	PTH 1, 4.7 km West of PTH 41	2009
31	AVC	PTH 75, 2.8 km North of PR 243	2009
55	AVC	PTH 1, 3.9 km West of PR 334	2009
M61	WIM/AVC	PTH 1, 8.9 km East of PR 302	2009
M63	WIM/AVC	PTH 75, 5.1 km South of PR 210	2009
M64	WIM/AVC	PTH 100, West of Symington Road	2009
M65	WIM/AVC	PTH 1, 7.0 km West of PR 350	2009

Note: AVC and WIM data provided by MHTIS

Table 26: Manual Body Type Survey Count Locations

Location	Date	Day of Week	Time of Day
Headingley Weigh Scale	26-Jan-10	Tuesday	1200-2400
	27-Jan-10	Wednesday	0000-2230
	28-Jan-10	Thursday	0000-2300
	29-Jan-10	Friday	0000-2300
	01-Feb-10	Monday	0800-1200
			1700-2300
	02-Feb-10	Tuesday	0800-1200
Emerson Weigh Scale	15-Feb-10	Monday	0830-1600
	16-Feb-10	Tuesday	0730-2000
	17-Feb-10	Wednesday	0700-2015
	18-Feb-10	Thursday	0940-2010
	19-Feb-10	Friday	0700-2030
West Hawk Weigh Scale	15-Feb-10	Monday	0800-1600
	16-Feb-10	Tuesday	0800-2230
	17-Feb-10	Wednesday	0800-1600
	18-Feb-10	Thursday	0800-2230
	19-Feb-10	Friday	0800-2215
Inkster Blvd and Perimeter Hwy	20-Aug-07	Monday	0930-1300
			1400-1600
	20-Feb-08	Wednesday	1430-1730
	22-Feb-09	Sunday	0000-1000
			1000-1200
			1300-1430
	26-Feb-09	Thursday	1900-2300
	28-Feb-09	Saturday	0530-1000

Note: Counts performed by UMTIG

Table 27: Titan Turning Counts

Station	Location	Intersection Legs	Date
150	PR 457 & PR 468	NB & WB	13-Mar-04 17-Mar-04
200	PTH 1 & PTH 83 W JCT	EB	15-Mar-04 17-Mar-04
201	PTH 1 & Oakland Rd	NB	23-Mar-04 25-Mar-04 02-Jun-04 03-Jun-04
640	PTH 1 & PTH 13	EB & WB	14-Jul-05 15-Jul-05
642	PTH 1 & PR 424	EB & WB	20-Apr-06
703	PTH 100 & St. Mary's Rd	EB	02-Jul-02 03-Jul-02
1367	PTH 12 & PR 210	NB & SB	7-Jun-05 10-Jun-05
1529	PTH 100 & PR 330	EB & WB	17-May-06 19-May-06
1531	PTH 75 & PTH 100	EB & WB	26-Jun-06 28-Jun-06
1732	PTH 75 & PTH 23 S JCT	SB	13-Dec-07 14-Dec-07
2353	PTH 1 & PR 340	WB	24-Jun-08
2354	PTH 1 & PR 468	WB	03-Jul-08 05-Jul-08
2356	PTH 1 & PR 501	EB & WB	7-Jun-08 13-Jun-08
2462	PTH 75 & PR 246	EB & WB	07-Jan-08 09-Jan-08

Note: Manual turning movement classification (Titan) counts provided by MHTIS
Multiple turning movement counts are averaged